This is a reproduction of a library book that was digitized by Google as part of an ongoing effort to preserve the information in books and make it universally accessible.

Google books

https://books.google.com

Digitized by Google

4°

I.Q. ~~Papers~~

EX LIBRIS

DES MUSEUMS VON
MEISTERWERKEN DER
NATURWISSENSCHAFT
u. TECHNIK · MÜNCHEN

ZB 6658

Bibliothek des Deutschen Museums
057002654772

Digitized by Google

Digitized by Google

Digitized by Google

QUARTERLY PAPERS

ON

ENGINEERING.

VOLUME III.

NUMEROUS ENGRAVINGS ON COPPER AND WOOD.

EDITED AND PUBLISHED BY

LONDON:
59, HIGH HOLBORN.

MDCCCXLV.

Digitized by Google

DEUTSCHES MUSEUM MÜNCHEN · BIBLIOTHEK ·

LONDON:
GEORGE WOODFALL AND SON,
ANGEL COURT, SKINNER STREET.

Digitized by Google

TO

GEORGE RENNIE, ESQ., C.E., F.R.S., F.R.G.S.,

ETC., ETC.,

THIS VOLUME,

BEING THE THIRD DEVOTED TO SUBJECTS CONNECTED WITH THE PROFESSION OF WHICH HE IS SO DISTINGUISHED A MEMBER,

IS INSCRIBED, WITH MUCH ESTEEM,

BY HIS VERY HUMBLE SERVANT,

JOHN WEALE.

JANUARY 25TH, 1845.

Digitized by Google

Digitized by Google

PREFACE.

THIS Treatise on Heat is neither a work purely theoretical nor a mere select description of apparatus. In the different modes of employing heat, I have at all times examined the conditions to be fulfilled, the advantages and inconveniences of each system, and have endeavoured to deduce from experiments made on a large scale or under suitable circumstances, formulæ or rules of easy application, which may serve as a guide to practical men; nevertheless, from the complication of the phenomena and the absence of sufficiently accurate data, I have frequently been obliged to limit myself to mere indications.

This work, being a summary of part of the course delivered by me at the *Ecole Centrale* since its foundation, differs considerably from the first edition of my Treatise on Heat, not only in the distribution of the matter, in the number as well as the nature of the plates, but more particularly in the numerous additions required by the advancement of industry. This book should therefore be considered rather as a new work than a reimpression.

The tables of contents at the end of each volume will indicate the order followed. In the first chapter, I have assembled the principal physical facts of frequent recurrence in practice. After which I have successively examined the materials used in combustion, the movement of air produced by compression and by heat, chimneys, fire-places, and the transmission of heat. Here we terminate the observations which precede the different modes of applying heat.

I have afterwards examined in detail the apparatus used in vaporization, evaporation, and drying, as well as those destined for the heating of air, liquids, and solids.

A chapter is devoted to the development of the laws of cooling, and includes the results of experiments which I have made on the transmission of heat through slow conducting substances, especially those used in construction.

Finally, in the concluding chapter, which treats of the salubrity (*assainissement*) of domestic dwellings and public institutions, I have pointed out the princi-

Digitized by Google

ples which should serve as a guide in the different systems of warming and ventilating.

Notwithstanding an extended minute research, and the information supplied by several distinguished engineers, still this work will be found in parts deficient; but these deficiencies are in reference to subjects in which the present state of science refuses a solution[a].

[a] *Note by the Author.*—In the correction of the proofs of the text and plates, as well as in verifying the calculations, I have been materially assisted by Mr. Thauvin, formerly a pupil of the *Ecole Centrale.*

Digitized by Google

CONTENTS OF VOLUME III.

PART V.

PART VI.

Digitized by Google

Digitized by Google

TREATISE ON HEAT,

CONSIDERED IN ITS APPLICATION.

BY E. PÉCLET,

INSPECTOR-GENERAL OF THE UNIVERSITY; PROFESSOR OF PHYSICS APPLIED TO THE ARTS AT THE ECOLE CENTRALE; MEMBER OF THE PHILOMATHIC SOCIETY; OF THE SOCIETY OF ENCOURAGEMENT, ETC.

SECOND EDITION, ENTIRELY REMODELLED.

VOL. I.

Digitized by Google

Digitized by Google

A

TREATISE ON HEAT,

CONSIDERED IN ITS APPLICATION.

CHAPTER THE FIRST.

PRINCIPAL FACTS RELATIVE TO THE PHYSICAL THEORY OF HEAT.

SECT. I. TEMPERATURE. THERMOMETERS.

1. In these introductory remarks, we state the facts as observed, and the laws relative to these facts, but at the same time without any demonstration; for the latter, we must refer to elementary works on physics.

2. When a body is heated, we say its temperature is increased, and that it is diminished when cooled, and that substances are of the same temperature when, by their contact, their condition in reference to heat is invariable, though at the same time affecting our senses very differently. It has been agreed to measure the temperature of bodies by the variation of their volume, which always accompanies a change of temperature; and, as the temperature of melting ice and that of boiling water under a pressure of $0^m.76$ centimètres (30 inches) is invariable, it has been found convenient to take for degree of temperature, the increased heat corresponding to an increased volume of the thermometrical body, equal to $\frac{1}{100}$ of the increase of volume which it undergoes in passing from the temperature of melting ice to that of boiling water, under the pressure of $0^m.76$ centimètres (30 inches)[a].

[a] It may be as well to remark here, that the thermometer referred to throughout this work (unless otherwise particularly indicated) is the *centigrade*, or that in most general use in France. We have also allowed the French *mètre*, as the unit of length and capacity, to remain as in the original text, as the reduction of equivalent temperatures or measures, is a matter of easy arithmetical calculation; rules for which, free from mathematical formulæ, are to be found in many elementary English works; those for the reduction

Digitized by Google

But as the expansion of all substances is not uniform, similar intermediate temperatures to those of melting ice or boiling water would be represented by different numbers, when different thermometrical bodies were employed. We are therefore obliged to determine on the nature of thermometrical substances. For this purpose the gases have been chosen, as their expansion is similar, and the effect of heat on these substances is independent of their nature, and less complicated in their action than with liquids or solids. But as the expansion of mercury is, through a very extensive range, similar to the gases, we may employ indifferently air or mercury. Alcohol is also used as a thermometrical substance, but as its expansion is very irregular, at least when compared with mercury, these instruments are graduated in determining a number of points on the scale by comparison with a standard mercurial thermometer.

3. Three different thermometrical scales are employed; the centigrade scale, which comprises 100 divisions between melting ice and boiling water; the thermometer of Reaumur containing 80°; and Fahrenheit's thermometer, which is marked 32° for the temperature of melting ice, and 212° for that of boiling water. In designating the indications of these three scales under the same circumstances by C, R and F, we evidently have,

$$C = \frac{5}{4}R \text{ and } C = (F - 32)\frac{5}{9}.$$

4. As it is impossible to procure capillary tubes perfectly cylindrical, when we require to make very accurate observations, tubes are employed, divided into parts of equal capacity; we mark the indications of the scale at will, which correspond to the temperatures of melting ice and boiling water, and we easily deduce from these numbers the temperature answering to any indication on the scale. Where precision is required, the point indicated by melting ice is frequently verified, as there is a variation, at least during a certain time, caused by an internal action of the glass.

5. Air thermometers are formed, as mercurial thermometers, with small capillary tubes, terminating in a bulb; but the tube is open at the upper end, and the bulb,

of the thermometer, with tables, will be found in "*Templeton's Engineer's Pocket Book*," page 10, 1844. In addition to the comparison of the mètre with the foot in decimals, we also give these comparisons in vulgar fractions, as perhaps more familiar to some of our readers.

COMPARISON OF VALUE OF FRENCH METRE AND ENGLISH FOOT.

Mètre $=3.280899$ ft., or 3 ft. $3\frac{11}{30}$ in. or 3 ft. $3\frac{1}{2}$ in. and $\frac{1}{30}$.
Decimètre $=3.937079$ in., or 3 in. and $\frac{19}{20}$ of an inch.
Centimètre $=0.3937079$ in., or about $\frac{5}{12}$ of an inch.
Millimètre $=0.03937079$ in., or about $\frac{1}{24}$ of an inch.

Digitized by Google

as well as part of the stem containing dry air, is separated from the external atmosphere by a bubble of quicksilver. The stem is divided into parts of equal capacity, the volume of which is a known fraction of the bulb. In designating by V and V′ the volume of air of the instrument at the temperature of melting ice and at the temperature T which we wish to determine, and by P and P′ the pressure of the atmosphere in both cases, and by a, the coefficient of the expansion of the air, we have

$$T = \frac{P'V' - PV}{aPV}.$$

In this formula we neglect the expansion of the glass, as being 150 times less than that of the air.

6. Thermometers are subject to two kinds of sensibility, the one which serves as an indication of slight variations of temperature, and the other that property which these instruments have of quickly assuming the temperature of the surrounding medium. To obtain the first mentioned sensibility, the stem should be of small diameter, and the bulb of considerable magnitude; on the contrary, for the latter we require to have the thermometrical mass very small. Thus, we cannot unite to a high degree these two properties in the same instrument.

7. When it is required to estimate small variations of temperature, an apparatus is used, formed of two glass balls fixed at the extremities of a thin glass tube bent in the form of the letter U. In the lower part is inclosed a bubble of coloured alcohol, or a long column of this liquid, which completely separates the air contained in the two bulbs. It may be easily imagined that the slightest difference of temperature in either of these bulbs will be indicated by a movement of the intervening liquid.

8. *Thermometers of maxima and minima.*—These instruments are intended to register the maximum or minimum of temperature in a certain given time. The most simple are made as the common thermometers, but placed horizontally; those intended to indicate the maxima, are of mercury, and have inclosed a small cylinder of steel, which the mercury pushes forward as the temperature increases, and which remains in the position assumed as the temperature lowers; those which mark the minima, are of alcohol, and their stem contains a small index or cylinder of enamel, which follows the liquid in the tube as the temperature lessens, but remains in that position should the temperature increase.

9. *Metallic Thermometers.*—The mode of action of all those instruments we have hitherto mentioned is owing to the difference of expansion of glass and liquids; others are employed in which the action depends on the unequal expansion of metals. These instruments are formed of two bars of different metals, and of unequal lengths, fixed together and united at one extremity; the unattached end of the shorter one

Digitized by Google

coincides with a scale on the other, which changes with the temperature. These instruments may be graduated as mercurial thermometers, but as the divisions become too small, their apparent expansion is in general increased by a system of levers. They are instruments but seldom employed.

10. *Measures of high temperature.*—The instruments used in measuring high temperatures are called *pyrometers*. That invented by Wedgwood is most generally used; its action is owing to the contraction which argil or potter's clay undergoes when submitted to heat; this contraction increases with the temperature, but subject to an unknown law changing with the nature of the clay, and within certain limits is owing to the water which this substance parts with; beyond this, it would seem to be solely attributable to a greater agglomeration of the materials. Wedgewood's pyrometers are composed of a brass plate on which two scales are fixed having a slight inclination towards each other, and between which is placed a small truncated cone of argil, which advances in the groove in proportion as it contracts. These cones should be composed of the same materials, contain equal proportions of water, and annealed at the same temperature. Wedgwood has adopted a low red heat as the zero point to which the cones are adjusted; the scale is divided into 240 parts. To ascertain the temperature of a furnace, one of these argil cones is introduced and placed in a crucible; when it has attained the temperature, it is taken out and permitted to cool, and then placed between the two scales and allowed to slide to the highest point it will reach. The degree of the scale to which it has arrived marks the temperature. In Wedgwood's pyrometer, the zero point corresponds to 580° of centigrade, and each division to 72°. These instruments are particularly useful in judging of the variations of temperature; they are only employed in the pottery furnaces[a].

11. As the fusible temperature of bodies is constant, it may be conceived that this phenomenon would serve to make known whether the temperature of a fire was above or below certain limits; and if we can procure substances, the fusibility of which is made manifest at increasing temperatures, but still of small increments, we arrive at a nearer approximation to the temperature of bodies as the fusible point of the substances employed is less distant. Thus, for example, if we place in a heating furnace, tin, lead, and zinc, in three separate vessels, the melting point of these metals being 210°, 260°, and 360°, if the tin alone is fused, the temperature of the furnace is between 210° and 260°. But as the melting point of the simple metals is so very different, these indications are too distant. M. J. Prinsep formed alloys of

[a] Lardner says, Page 54, Treatise on Heat, "This instrument has been long out of use."

Digitized by Google

silver and gold, or of gold and platina, of different standards, which included all the temperatures comprised between that of the melting of silver and platina, at the same time as numerous as may be desired, and permitting us to fix exactly the nature of the alloy fusible at a given temperature. Prinsep formed ten alloys with gold and silver, containing quantities of gold increasing by $\frac{1}{10}$; and a hundred alloys of gold and platina, in which the latter was successively augmented by $\frac{1}{100}$. To judge of the temperature of a fire, we place in it a crucible of calcined bones, divided into numbered compartments, in each of which is placed a piece of the alloy the size of a pin's head; when the crucible has acquired the temperature of the fire, it is withdrawn, taking care to observe the alloy at which fusion has ceased. Prinsep designated this alloy by the two initial letters of the mixed metals, and before one of them is placed the number indicating the proportion which it forms of the alloy. Thus, for example, if the alloy the most difficult to act on is composed of nine parts silver and one of gold, it is marked S 0, 1 G. This is a very convenient method to establish a comparison between two fires; but, to arrive at an exact estimate, at least so that the latter may be compared with the temperature indicated by an ordinary thermometer, it is necessary to know the fusible point of each alloy in degrees of the air-thermometer.

This has been determined by M. Prinsep for the fusion of silver and several alloys of gold, by measuring the expansion of air inclosed in a golden vessel. We here give the results of these experiments.

Red heat	649° cent.
Orange heat	899
Melting of silver	999
Silver with $\frac{1}{10}$ gold	1048
Ditto with $\frac{1}{4}$ gold	1121

12. When a heated substance is immersed in water, the temperature which the liquid acquires depends on the primitive temperature and specific heat of the two bodies; then if we know the final temperature of the water and of three other quantities, we can calculate the fourth. In this manner it is, that we determine the specific heat of substances. We can also employ this method to determine the temperature of a furnace. Let us suppose that we place in a furnace a piece of iron the weight of which we will call P, and that it is withdrawn when it has acquired the temperature; that we then immerse it in a vessel, containing a weight P′ of water at the tempera-

Digitized by Google

ture t, and supposing that the temperature of the water is raised to t'; in calling x that of the furnace, and c the specific heat of iron, we shall evidently have

$$\mathrm{P}c\,(x-t') = \mathrm{P}'\,(t'-t) \quad \text{whence} \quad x = \frac{\mathrm{P}'\,(t'-t)}{\mathrm{P}c} + t'.$$

This method might give very exact results if the specific heat of iron was constant; but as it varies with the temperature, we can only by these means obtain a rough approximation. Nevertheless, with a little precaution, we can determine the temperature of a furnace within 0.1, and such an approximation is in general sufficient.

13. We can also obtain the temperature of a furnace by thermo-electric currents. If we place in the end of a gun-barrel a platina wire in the direction of its axis and communicating at one of its extremities with a wire of a rheometer, and at the other end of the barrel another platina wire in connexion with the opposite extremity of the wire of the rheometer, and if we place the first mentioned end of the gun-barrel in a furnace, in maintaining at the same temperature all the other solders, deviations will take place in the needle of the rheometer, increasing with the temperature of the furnace, by which the latter can be measured, in admitting that the intensity of the current is in proportion to the difference of the temperatures of the two solders, iron and platina, as this has been authenticated for differences of temperatures through rather an extensive range.

SECT. II. RADIATED HEAT.

14. All substances, whatever may be their nature and temperature, give off heat, which is transmitted similar to light, and known under the name of radiated heat.

15. Radiated heat, in the same manner as light, moves with great velocity and in straight lines.

16. Rays of heat are reflected by polished surfaces; the rays of incidence and reflection are in the same normal plane at the surface of the point of incidence, and the two rays have equal inclinations to the normal. From this it will result, that rays of heat are influenced by reflectors as the rays of light.

17. The intensity of radiated heat varies in the inverse ratio of the square of the distance from its source. This is a necessary consequence of the divergence of the rays at their origin.

18. Bodies reflect heat in proportion as their surfaces are the more polished; but the nature of the substance has also a great influence.

Digitized by Google

TABLE OF THE REFLECTING POWER OF BODIES, BY LESLIE.

Brass	100
Silver	90
Tin-foil	85
Steel	70
Lead	60
Tin-foil softened with mercury	10
Glass	10
Glass oiled	5
Lamp-black	0

According to Melloni, the different liquids, delf-ware, enamels, and marbles possess a reflecting power nearly similar to that of water.

19. *Radiating Power.*—The intensity of rays of heat of the same section is constant, whatever their inclination may be on the radiating substance; from which it will follow, that the intensity of rays emitted by the same extent of surface, is proportioned to the line of the angle formed by the direction of the rays with that surface.

TABLE OF THE RADIATING POWER OF A CERTAIN NUMBER OF BODIES, BY LESLIE.

Lamp-black	100
Water	100
Writing-paper	98
Crown-glass	90
China ink	88
Ice	85
Quicksilver	20
Clean lead	19
Iron polished	15
Tin, silver, gold	12

ACCORDING TO MELLONI.

Lamp-black	100
Carbonate of lead	100
Isinglass	91

Digitized by Google

China ink	85
Gum-lac	72
Metallic surface	12

20. In metals, the state of the surface has a considerable influence on the radiating power; the latter is greater when the surface is tarnished than when polished. In non-metallic bodies, the radiating power seems to be uninfluenced by the state of the surface.

21. *Absorption.*—The absorbent power of substances varies in the same manner as the radiating power, but changes with the nature of the sources of heat.

Melloni in causing rays of the same intensity to fall on different substances, but derived from different sources, has obtained the following results.

	Lamp.	Platina Incandescent.	Copper at 400°.	Copper at 100°.
Lamp-black	100	100	100	100
Carbonate of lead	53	56	89	100
Isinglass	52	54	64	91
China ink	96	95	87	85
Gum-lac	43	47	70	72
Metallic surface	14	13.5	13	13

21 *bis.* The power of radiation and absorption is equal.

22. *Transmission of radiated heat through solids and transparent liquids.*—The rays of heat pass through diaphanous bodies in a similar manner to those of light; to this well known fact, Melloni has recently added many new ones; we shall point out those which may be of importance to our present subject.

23. The quantity of heat passing through *diathermanic* bodies (it is thus that Melloni designates those substances penetrated by radiated heat) is so much the greater, every thing else being equal, the more polished their surface.

24. The quantity of heat which penetrates plates of different substances, but of the same thickness, is very variable, and it is independent of their transparency or colour. Of all the diathermanic substances, rock-salt gives the freest passage to heat, and alum, the most difficult of penetration.

25. The quantity of heat passing through a diathermanic plate diminishes in proportion with its thickness, but in a much slower ratio. Rock-salt forms an exception; it allows the same quantity of heat to penetrate independent of its thickness. Common glass is penetrated by about 0.70 of the rays emanating from a flame, by

Digitized by Google

0.45 of those given off by an incandescent metal, and by 0.70 of those rays from bodies below a red heat.

SECT. III. PROPAGATION OF HEAT THROUGH BODIES.

26. When a homogeneous plate has both of its surfaces maintained at a constant temperature, the quantity of heat which penetrates the plate is in proportion to the temperature of the two surfaces and in the inverse ratio of its thickness.

For plates of different substances of the same thickness and difference of temperature of surfaces, the quantities of heat which penetrate them are in the following proportions:

Gold	1000
Platina	981
Silver	973
Copper	898
Iron	374
Zinc	363
Tin	303
Lead	179
Marble	23
Porcelain	12
Baked earth (or brick earth)	11

27. The worst conductors are those substances composed of very fine filaments with few points of contact, such as, cotton, wool, down, bran, straw, &c.

28. The propagation of heat in liquids is communicated as in solids from molecule to molecule; but the effect produced by this mode of heating is nearly inappreciable. Liquids are chiefly heated by the currents produced in their mass, when heat is applied to the bottom of the vessel in which they are contained.

29. Gases absorb but a very small portion of the rays of heat which pass through them, and cannot be heated as liquids, but by currents which successively bring the different parts in contact with the surface of the heated solid. This movement takes place spontaneously when the source of heat is placed under the gas.

SECT. IV. LAWS OF HEATING AND COOLING.

30. When a liquid inclosed in a vessel exposed to the air is at a higher temperature than the surrounding medium, the liquid cools both by the difference of the radia-

Digitized by Google

tion of the vessel and the atmosphere in which it is placed, and by the movement of the surrounding air.

In designating by A the primitive temperature of the liquid, T its temperature after a time t, a a constant coefficient, and by V the velocity of cooling, that is, the cooling which takes place in a unity of time, for an excess T of temperature of the substance above that of the surrounding medium, in supposing that this excess is constant, we have

$$\log T = \log A - \frac{at}{2.30}; \text{ and } V = a\,T.$$

By means of the first, we can find the temperature T after the time t, when we know the value of a which depends on the weight of the liquid, the size and nature of the vessel, and which we can determine by an experiment. The second gives the velocity of cooling, when we know the excess of temperature of the body above that of the surrounding atmosphere.

These formulæ, which we owe to Newton, are exact when the difference of temperature of the liquid and air does not exceed 20° or 30°; beyond this they become more and more inaccurate; nevertheless, they are sufficient on many occasions.

In the course of a remarkable series of experiments by Petit and Dulong on the laws of cooling, they have been led to the discovery of a formula much more accurate than that of Newton, for representing the velocity of cooling in functions of the excess of the temperature of bodies above that of the surrounding medium; but it is more complicated and difficult of application.

SECT. V. EXPANSION OF SOLIDS.

31. *Expansion of Solids.*—The following table includes the results of experiments by several philosophers. Unity is the volume of the substances at 0°.

Digitized by Google

LINEAR DILATATION OF SOLIDS, FROM 0° TO 100°.

Names of Substances.	Decimal Fractions.	Vulgar Fractions.
LAPLACE AND LAVOISIER.		
English flint glass	0.00081166	1/1248
Platina (Borda)	0.00085655	1/1167
French glass with lead	0.00087199	1/1147
Glass tube without lead	0.00087572	1/1142
Ditto	0.00089694	1/1115
Ditto	0.00089760	1/1114
Ditto	0.00091750	1/1090
Glass St. Gobain	0.00089089	1/1122
Steel not tempered	0.00107880	1/927
Ditto	0.00107915	1/927
Ditto	0.00107960	1/926
Steel tempered yellow, annealed at 65°	0 00123956	1/807
Soft-forged iron	0.00122045	1/819
Round iron, wire-drawn	0.00123504	1/812
Gold procured by parting	0.00146606	1/682
Gold, Paris standard, annealed	0.00151361	1/661
Ditto, unannealed	0.00155155	1/645
Copper	0.00171220	1/584
Ditto	0.00171733	1/582
Ditto	0.00172240	1/581
Brass	0.00186670	1/535
Ditto	0.00187821	1/533
Ditto	0.00188970	1/529
Silver, Paris standard	0.00190868	1/524
Silver of cupel	0.00190974	1/524
Indian or Malacca tin	0.00193765	1/516
Falmouth tin	0.00217298	1/462
Lead	0.00284836	1/351
SMEATON.		
Crown glass (barometer tubes)	0.00083333	1/1175
Regulus of antimony	0.00108333	1/923
Steel	0.00115000	1/870
Steel, tempered	0.00122500	1/816
Iron	0.00125833	1/795
Bismuth	0.00139167	1/719
Hammered copper	0.00170000	1/588
Copper 8 parts, tin 1	0.00181667	1/550
Cast brass	0.00187500	1/533

Names of Substances.	Decimal Fractions.	Vulgar Fractions.
Brass 16 parts, tin 1	0.00190833	1/524
Brass wire	0.00193333	1/517
Speculum metal	0.00193333	1/517
Solder, copper 2 parts, zinc 1	0.00205833	1/486
Pure tin	0.00228333	1/438
Grain tin	0.00248333	1/403
Soft solder, tin 1 part, lead 2	0.00250533	1/399
Zinc, 8 parts, tin 1, a little hammered	0.00269167	1/372
Lead	0.00286667	1/349
Zinc	0.00294167	1/340
Zinc, hammered out 1/12	0.00310833	1/322
MAJOR-GENERAL ROY.		
Glass tube	0.00077550	1/1289
Glass rod	0.00080833	1/1237
Cast iron prism	0.00111000	1/901
Steel rod	0.00114450	1/874
Hamburgh brass	0.00185550	1/539
English brass, in a rod	0.00189296	1/528
English brass, in a trough form	0.00189450	1/528
TROUGHTON.		
Platina	0.00099180	1/1008
Steel	0.00118990	1/840
Iron, wire-drawn	0.00144010	1/694
Copper	0.00191880	1/521
Silver	0.00208260	1/480
WOLLASTON.		
Palladium	0.00100000	1/1000
DULONG AND PETIT.		
Platina, from 0° to 100	0.00088420	1/1161
Ditto, from 0° to 300	0.00091827	1/1089
Glass, from 0° to 100	0.00086133	1/1161
Ditto, from 0° to 200	0.00094836	1/1032
Ditto, from 0° to 300	0.00101084	1/987
Iron, from 0° to 100	0.00118210	1/846
Ditto, from 0° to 300	0.00146842	1/681
Copper, from 0° to 100	0.00171820	1/582
Ditto, from 0° to 300	0.00188324	1/531

Digitized by Google

Laplace and Lavoisier have discovered that the expansion of the same substances was uniform from 0° to 100, that is to say, for the same number of degrees comprised in these limits, the length of bars increased by a similar fraction of their lengths from 0°.

Nevertheless, Petit and Dulong found, that for the same number of degrees, the expansion was augmented with the temperature, measured by the air thermometer. Strictly speaking, this increase is nearly inappreciable within the limits of 0° to 100; but from 0° to 300 it is rather considerable, as may be seen from the preceding tables.

32. The superficial expansion of substances by heating is obviously equal to double the linear expansion, and the expansion of volume is treble that of the latter; so that by calling L, S and V the length, the surface and volume of a body at 0°, L′, S′ and V′ the length, the surface and volume of the same body at $t°$, and δ the linear dilatation for 1°, we have

$$L' = L(1 + \delta t); \quad S' = S(1 + 2\delta t); \quad V' = V(1 + 3\delta t).$$

33. Homogeneous hollow substances increase in volume by an addition of temperature in the same proportion as if solid.

34. *Expansion of liquids.*—According to the experiments of Dulong, the dilatation of air and mercury is similar as far as 100°; but, in commencing from the new coefficient of the expansion of air, this similitude is extended still further; for if a mercurial thermometer indicates 360°, an air thermometer, under the same circumstances, will mark 350°. We may thus admit without material error, that mercurial and air thermometers coincide to the highest temperatures.

The coefficient of dilatation of mercury is $\frac{1}{5550}$.

The coefficient of apparent dilatation of mercury in the glass is $\frac{1}{6480}$.

35. The expansion of other liquids in comparison with that of mercury is very irregular. Water has a maximum density which corresponds to 4°.1.

Digitized by Google

DENSITY AND VOLUME OF WATER FROM 0° TO 30 CENTIGRADE, BY HALLSTROM.

Temperature.	In taking for Unity the Volume and Density of Water at 0°.		In taking for Unity the Density and Volume at 4°.1.	
	Density.	Volume.	Density.	Volume.
0°	1.0	1.0	0.9998918	1.0001082
1	1.0000466	0.9999536	0.9999382	1.0000617
2	1.0000799	0.9999202	0.9999717	1.0000281
3	1.0001004	0.9998996	0.9999920	1.0000078
4	1.00010817	0.9998918	0.9999995	1.0000002
4.1	1.00010824	0.99989177	1.0	1.0
5	1.0001032	0.9999968	0.9999950	1.0000050
6	1.0000856	0.9999144	0.9999772	1.0000226
7	1.0000355	0.9999445	0.9999472	1.0000527
8	1.0000129	0.9999872	0.9999044	1.0000954
9	0.9999579	1.0000421	0.9998497	1.0001501
10	0.9998906	1.0001004	0.9997825	1.0002200
11	0.9998112	1.0001888	0.9997030	1.0002970
12	0.9997196	1.0002804	0.9996117	1.0003888
13	0.9996160	1.0003841	0.9995080	1.0004924
14	0.9995005	1.0004997	0.9993922	1.0006081
15	0.9993731	1.0006273	0.9992647	1.0007357
16	0.9992340	1.0007666	0.9991260	1.0008747
17	0.9990832	1.0009176	0.9989752	1.0010259
18	0.9989207	1.0010805	0.9988125	1.0011888
19	0.9987468	1.0012548	0.9986387	1.0013631
20	0.9985615	1.0014406	0.9984534	1.0015490
21	0.9983648	1.0016379	0.9982570	1.0017560
22	0.9981569	1.0018465	0.9980489	1.0019549
23	0.9979379	1.0020664	0.9978300	1.0021746
24	0.9977077	1.0022976	0.9976000	1.0024058
25	0.9974666	1.0025398	0.9973587	1.0026483
26	0.9972146	1.0027932	0.9971070	1.0029016
27	0.9969518	1.0030575	0.9968439	1.0031662
28	0.9966783	1.0033328	0.9965704	1.0034414
29	0.9963941	1.0039189	0.9962864	1.0037274
30	0.9960993	1.0039160	0.9959917	1.0040245

Digitized by Google

APPARENT DILATATION OF DIFFERENT LIQUIDS IN THE GLASS.

Names of Substances.	Dilatation from 0° to 100°.	
Water	1/22	0.0466
Hydrochloric acid (sp. gr. 1.137)	1/27	0.0600
Nitric acid (sp. gr. 1.40)	1/9	0.1100
Sulphuric acid (sp. gr. 1.85)	1/17	0.0600
Sulphuric ether	1/14	0.0700
Olive and linseed oil	1/12	0.0800
Essence of turpentine	1/14	0.0700
Water saturated with sea-salt	1/20	0.0500
Alcohol	1/9	0.1100
Mercury	1/64	0.0156
TRUE EXPANSION FOR 1°.		
Mercury from 0° to 100°	1/5550	0.0180180
Mercury from 100° to 200°	1/5425	0.0184331
Mercury from 200° to 300°	1/5300	0.0188679

36. *Dilatation of Gases.*—All the gases are uniform in their expansion, at least through a range of temperature sufficiently removed from that corresponding to their liquefaction. This uniformity has led to their adoption as a measure of temperature.

The laws of expansion of gases were discovered about the same time by Gay-Lussac in France, and by Dalton in England. Charles had previously determined the uniform expansion of gases, but he had not measured the coefficient of dilatation. Dalton found 0.372 as the absolute dilatation from 0° to 100°, and maintained that the expansion for each degree was $\frac{1}{267}$ of the volume of the gas at a lower temperature, for example that from 20° to 21° the expansion was $\frac{1}{267}$ of the volume of the gas at 20°; whereas, according to Gay-Lussac, the expansion is $\frac{1}{267}$ or 0.00375 of the volume at 0°. The experiments since made by Petit and Dulong have confirmed the accuracy of Gay-Lussac's law. But still more recent experiments by Rudberg give 0.00364 for coefficient of expansion of the gases, and the same number was obtained by Regnault; so that we shall adopt the latter.

37. In designating by V the volume of a gas at 0°, by V′ its volume at t°, under the same pressure we have

$$V' = V\,(1 + 0.00364\,.\,t). \tag{1}$$

If V was the volume of a gas at t°, V′ the volume of the same gas at t'°, still under the same pressure, we should have

$$V' = V\frac{1 + 0.00364\,t'}{1 + 0.00364\,t}\,;\ \text{or}\ V' = V\,(1 + 0.00364\,(t' - t.)). \tag{2}$$

Digitized by Google

The latter formula has been obtained in neglecting the terms which comprise the square of 0.00364; as it is much more simple than the former, and in reality as exact, we shall adopt it in preference.

If the volume V was at the pressure p, and the volume V′ at the pressure p', we should have

$$V' = \frac{Vp}{p'}\left(\frac{1 + 0.00364t'}{1 + 0.00364t}\right),$$

and in neglecting the square of 0.00364, we have

$$V' = \frac{Vp}{p'}\left(1 + 0.00364\,(t' - t)\right). \qquad (3)$$

SECT. VI. STEAM.

38. When a vapourable liquid is inclosed in a vacuum, it is immediately filled by all the steam which it can form at the temperature of the liquid. If the space is increased fresh steam is given off, so that the elastic force and density of the steam are constant; if the space is diminished, a certain portion of the steam is condensed, so that the remaining part retains its original tension and density. But to maintain the first mentioned condition permanent, we must have a supply of heat to furnish the liquid with that necessary for the formation of steam; and for the second, the vessel must have the power of absorbing and parting with the heat resulting from a partial condensation of the steam. In admitting the same hypothesis, if we increase or diminish the temperature of the liquid, during these variations of space, the steam preserves the tension and maximum density corresponding to the temperature of the liquid.

39. Saturated steam is that which has a maximum tension and maximum density corresponding to its temperature.

40. If we suppose a space saturated with steam and free from liquid, and that the vessel neither furnishes nor absorbs heat, by increasing the volume of the space, the density, tension and temperature of the steam will be decreased; and in diminishing the space, the density, tension and temperature of the steam will be increased, and in the latter case, it is not certain if a part of the steam is not condensed. In both these circumstances, according to M. de Pambour, the steam continues saturated, that is, it has at all times the maximum tension corresponding to its temperature, and in the latter no condensation takes place.

41. In the circumstances we have spoken of, if we heat and increase the space containing the steam, its elastic force will vary as that of a permanent gas. In general, unsaturated steam is influenced by the changes of temperature and pressure similar to a permanent gas, provided these changes do not produce saturation.

42. The following tables comprise the tension of the vapour of water at different temperatures.

Digitized by Google

ELASTIC FORCE OF THE VAPOUR OF WATER, FROM 20° TO 100° AND PRESSURES ON ONE SQUARE CENTIMETRE.

Degrees of centigrade thermometer.	Tension of steam in millimètres.	Pressure on a square centimètre.	Degrees of centigrade thermometer.	Tension of steam in millimètres.	Pressure on a square centimètre.
degr.	millim.	kilogr.	degr.	millim.	kilogr.
—20	1.333	0.0018	49	84.370	0.11662
—15	1.879	0.0026	50	88.743	0.12056
—10	2.631	0.0036	51	93.301	0.12676
— 5	3.660	0.0050	52	98.075	0.13325
0	5.059	0.0069	53	103.060	0.13999
1	5.393	0.0074	54	108.270	0.14710
2	5.749	0.0078	55	113.710	0.15449
3	6.123	0.0084	56	119.390	0.16220
4	6.523	0.0089	57	125.310	0.17035
5	6.947	0.0094	58	131.500	0.17866
6	7.396	0.0101	59	137.940	0.18736
7	7.871	0.0107	60	144.660	0.19653
8	8.375	0.0114	61	151.700	0.20610
9	8.909	0.0122	62	158.960	0.21586
10	9.475	0.0129	63	166.560	0.22639
11	10.074	0.0137	64	174.470	0.23758
12	10.707	0.0146	65	182.710	0.24823
13	11.378	0.0155	66	191.270	0.25986
14	12.087	0.0165	67	200.180	0.27196
15	12.837	0.0170	68	209.440	0.28456
16	13.630	0.0186	69	219.060	0.29761
17	14.468	0.0197	70	229.070	0.31121
18	15.353	0.0209	71	239.450	0.32532
19	16.288	0.0222	72	250.230	0.33996
20	17.314	0.0235	73	261.430	0.35518
21	18.317	0.0250	74	273.030	0.37094
22	19.447	0.0265	75	285.070	0.39632
23	20.577	0.0281	76	297.570	0.40428
24	21.805	0.0297	77	310.490	0.42184
25	23.090	0.0314	78	323.890	0.44004
26	24.452	0.0334	79	337.760	0.45888
27	25.881	0.0353	80	352.080	0.47834
28	27.390	0.0374	81	367.000	0.49860
29	29.045	0.0396	82	382.380	0.51950
30	30.643	0.0418	83	398.280	0.54110
31	32.410	0.0440	84	414.730	0.56345
32	34.261	0.0465	85	431.710	0.58632
33	36.188	0.0492	86	449.260	0.61036
34	38.254	0.0520	87	467.380	0.63498
35	40.404	0.0549	88	486.090	0.66040
36	42.743	0.0581	89	505.380	0.68661
37	45.038	0.0612	90	525.28	0.71364
38	47.579	0.0646	91	545.80	0.74152
39	50.147	0.0681	92	566.95	0.77026
40	52.998	0.0720	93	588.74	0.79986
41	55.772	0.0758	94	611.18	0.83035
42	58.792	0.0799	95	634.27	0.86172
43	61.958	0.08418	96	658.05	0.89402
44	65.627	0.08916	97	682.59	0.92736
45	68.751	0.09340	98	707.63	0.96138
46	72.393	0.09835	99	733.46	0.99448
47	76.205	0.10353	100	760.00	1.03253
48	80.195	0.10900			

Digitized by Google

Within the limits of temperature of this table, the temperature and elastic force are united by the formula

$$t = 85\sqrt[6]{f} - 75,$$

in which t represents the temperature in degrees of centigrade, and f the elastic force in centimètres of mercury. We are indebted for this empirical formula to Tredgold.

43. *Tension of the vapour of water at high temperatures.*—The measure of the elastic force of the vapour of water at high temperatures presents considerable difficulties, and is accompanied with some risk. Until the publication of the experiments of MM. Dulong and Arago in 1830, we were ignorant of the elastic force of steam above eight atmospheres, and the results obtained by different philosophers were very discordant. The following table gives the elastic force of the vapour of water, and the corresponding temperatures from 1 to 24 atmospheres, as observed by the two above mentioned philosophers, and the results of calculation from 24 to 50 atmospheres. We place alongside the pressure in kilogrammes with which the steam acts at these temperatures, as these numbers may be useful in practice.

Digitized by Google

TABLE OF ELASTIC FORCE OF THE VAPOUR OF WATER AT DIFFERENT TEMPERATURES.

Elasticity of Steam in taking the Atmospheric Pressure as Unity.	Column of Mercury at 0° which measures the Elasticity.	Corresponding Temperature by Centigrade Mercurial Thermometer.	Pressure on a square Centimètre.
	millim.		kilogr.
1	0.7600	100°	1.033
1½	1.1400	112.2	1.549
2	1.5200	121.4	2.066
2½	1.9000	128.8	2.582
3	2.2800	135.1	3.099
3½	2.66	140.6	3.615
4	3.04	145.4	4.132
4½	3.42	149.06	4.648
5	3.80	153.08	5.165
5½	4.18	153.8	5.681
6	4.56	160.2	6.198
6½	4.94	163.48	6.714
7	5.32	166.5	7.231
7½	5.70	169.37	7.747
8	6.08	172.1	8.264
9	6.84	177.1	9.297
10	7.60	181.6	10.33
11	8.36	186.03	11.363
12	9.12	190.0	12.396
13	9.88	193.7	13.429
14	10.64	197.19	14.462
15	11.40	200.48	15.495
16	12.16	203.60	16.528
17	12.92	206.57	17.561
18	13.68	209.4	18.594
19	14.44	212.1	19.627
20	15.20	214.7	20.660
21	15.96	217.2	21.693
22	16.72	219.6	22.726
23	17.48	221.9	23.759
24	18.24	224.2	24.792
25	19.00	226.3	25.825
30	22.80	236.2	30.990
35	26.60	244.85	36.155
40	30.40	252.55	41.320
45	34.20	259.52	46.485
50	38.00	265.89	51.650

Digitized by Google

44. The numbers comprised in this last table answer to the formula

$$t = \frac{\sqrt[5]{f} - 1}{0.7153},$$

in which t represents the temperature in degrees of centigrade, commencing from 100°, in taking for unity the intervals of 100°, and f the elastic force in atmospheres of $0^m.76$. But from 1 to 4 atmospheres, the formula of Tredgold is more suited to practice.

45. For all other vapourable liquids, the tension may be calculated approximately by the law discovered by Dalton, *that the elastic force of the vapour of different liquids is equal at temperatures equally distant from that of their boiling points.*

46. *Density of Steam.*—The density of steam of any particular liquid is, an invariable quantity expressed by the proportion of the weight of two equal volumes of steam and air at the same temperature and pressure.

47. The following table includes the density of steam of a certain number of liquids.

Names of Liquids.	Density of Steam.	Boiling Point.
Water	0.6235	100
Hydrocyanic acid	0.9476	26.50
Alcohol	1.6138	78
Hydrochloric ether	2.219	11
Sulphuric ether	2.5860	36
Sulphuret of carbon	2.6447	47
Oil of turpentine	5.0130	157
Hydriodic ether	5.4749	65

48. We designate the density of steam at a certain temperature and pressure, the number of times that the weight of a certain volume of that steam, at that temperature and pressure, contains the weight of the same volume of water at 4°.

49. The density of steam at a certain temperature and pressure, is equal to the tabular density multiplied by that of air at that temperature and pressure. The density d of the vapour of water at $t°$ and under the pressure p is expressed by the formula

$$d = 0.6235 \frac{p}{0.76\,(1 + at)}.0.0013.$$

50. The following table includes the tension and density of the vapour of water at different temperatures, as well as its volume, in reference to the water from which it is generated.

Digitized by Google

TABLE OF THE TENSION, DENSITY, AND VOLUME OF THE VAPOUR OF WATER AT DIFFERENT TEMPERATURES.

Temperature.	Tension.	Density.	Volume.	Temperature.	Tension.	Density.	Volume.
	millim.				millim.		
−20°	1.333	0.00000154	650588	47°	76.205	0.00006910	14472
−15	1.879	212	470898	48	80.195	7242	13809
−10	2.631	292	342984	49	84.370	7602	13154
− 5	3.660	398	251358	50	88.742	7970	12546
0	5.059	540	182323	51	93.301	8354	11971
1	5.393	573	174495	52	98.075	8753	11424
2	5.748	609	164332	53	103.060	9174	10901
3	6.123	646	154842	54	108.270	9606	10410
4	6.523	686	145886	55	113.710	0.00010054	9946
5	6.947	727	137488	56	119.390	10525	9501
6	7.396	772	129587	57	125.310	11011	9082
7	7.871	818	122241	58	131.550	11523	8680
8	8.375	867	115305	59	137.940	12044	8303
9	8.909	919	108790	60	144.660	12599	7937
10	9.475	974	102670	61	151.700	13179	7594
11	10.074	0.00001032	99202	62	158.960	13760	7267
12	10.707	1092	91564	63	166.560	14374	6957
13	11.378	1157	86426	64	174.470	15010	6662
14	12.087	1224	81686	65	182.710	15668	6382
15	12.837	1299	77008	66	191.270	16356	6114
16	13.630	1372	72913	67	200.180	17066	5860
17	14.468	1451	68923	68	209.440	17797	5619
18	15.353	1534	65201	69	219.060	18566	5386
19	16.288	1622	61654	70	229.070	19355	5167
20	17.314	1718	58224	71	239.450	20174	4957
21	18.317	1811	55206	72	250.230	21013	4759
22	19.417	1914	52260	73	261.430	21889	4569
23	20.577	2021	49487	74	273.030	22794	4387
24	21.805	2133	46877	75	285.070	23789	4204
25	23.090	2252	44411	76	297.570	24702	4048
26	24.452	2376	42084	77	310.490	25699	3891
27	25.881	2507	39895	78	323.890	26739	3741
28	27.890	2643	37838	79	337.760	27789	3599
29	29.045	2794	35796	80	352.080	28889	3462
30	30.643	2938	34041	81	367.000	30025	3331
31	32.410	3097	32291	82	382.380	31195	3206
32	34.261	3263	30650	83	398.280	32399	3087
33	36.188	3435	29112	84	414.730	33637	2973
34	38.254	3619	27636	85	431.710	34916	2864
35	40.404	3809	26253	86	449.260	36237	2760
36	42.743	4017	24897	87	467.380	37590	2660
37	45.038	4219	23704	88	486.090	38984	2565
38	47.579	4442	22513	89	505.380	40417	2474
39	50.147	4666	21429	90	525.280	41891	2387
40	52.998	4916	20343	91	545.800	43405	2304
41	55.772	5156	19396	92	566.950	44956	2224
42	58.792	5418	18459	93	588.740	46556	2148
43	61.958	5691	17572	94	611.180	48201	2075
44	65.627	6023	16805	95	634.270	49886	2005
45	68.751	6274	15938	96	658.050	51613	1938
46	72.393	6585	15185	97	682.590	53388	1873

Digitized by Google

TABLE—CONTINUED.

Temperature.	Tension.	Density.	Volume.	Temperature.	Tension.	Density.	Volume.
	millim.				millim.		
98°	707.630	0.00055191	1812	156.70°	4180.000	0.00280827	356
99	733.460	57055	1751	158.30	4370.000	292485	342
100	760.000	58955	1695	160.00	4560.000	304651	328
106.60	950.000	72391	1381	161.54	4750.000	315513	317
112.40	1140.000	85539	1169	163.25	4940.000	326828	306
117.10	1330.000	98324	1014	164.84	5130.000	338148	296
121.55	1520.000	0.00111652	896	166.42	5320.000	349393	286
125.50	1710.000	123923	806	167.94	5510.000	360606	277
128.85	1900.000	136636	732	169.41	5700.000	371783	269
132.15	2090.000	149056	671	170.78	5890.000	382907	261
135.00	2280.000	161453	619	172.13	6080.000	394110	254
137.70	2470.000	173739	576	173.46	6270.000	405198	247
140.35	2660.000	185886	538	174.79	6460.000	416123	240
142.70	2850.000	198020	505	176.11	6650.000	427182	234
144.95	3040.000	210067	476	177.40	6840.000	438111	228
146.76	3230.000	222731	449	178.68	7030.000	447955	223
149.15	3420.000	233938	428	179.89	7220.000	459873	217
151.15	3610.000	245763	407	180.95	7418.000	473858	212
153.30	3800.000	257363	389	182.00	7600.000	481690	208
155.00	3990.000	268956	392	215.00	23800.000	0.01570780	64

WEIGHT OF A CUBIC MÈTRE OF SATURATED STEAM AT DIFFERENT TEMPERATURES.

Temperature.	Weight in Grammes.	Temperature.	Weight in Grammes.
0°	5.3	55	102.20
5	7.3	60	126.10
10	9.7	65	159.20
15	13.10	70	196.40
20	17.30	75	238.80
25	22.70	80	293.60
30	29.70	85	355.70
35	39.00	90	426.10
40	49.90	95	507.40
45	63.70	100	590
50	71.00		

WEIGHT OF STEAM CONTAINED IN A SATURATED CUBIC MÈTRE OF AIR AT DIFFERENT TEMPERATURES, UNDER A PRESSURE OF $0^m.76$.

Temperature.	Weight in Grammes.	Temperature.	Weight in Grammes.
0°	5.2	55	88.74
5	7.2	60	105.84
10	9.50	65	127.20
15	12.83	70	141.96
20	16.78	75	173.74
25	22.01	80	199.24
30	28.51	85	227.20
35	37.00	90	251.34
40	46.40	95	273.78
45	58.60	100	295
50	63.63		

Digitized by Google

51. M. de Pambour has found, by a series of experiments (*par tâtonnement*), a formula by means of which we obtain the volume of a given weight of steam, merely in a function of the pressure; this formula is:

$$v=\frac{10000}{0.4227+5.2897\,p}$$

in which v represents the volume of steam in reference to the volume of water from which it is generated, and p the pressure in kilogrammes on the square centimètre. If the pressure was estimated in mètres of mercury, the formula should be

$$v=\frac{10000}{0.4227+7.14\,p}.$$

52. *Mixtures of Gas and Steam.*—When we pour liquid into a close vessel containing dry gas, we observe the following effects:—1st, Steam is but slowly formed, and it is not until after a certain time, more or less distant, that the gas is impregnated with all the steam that can be generated at the temperature of the liquid. 2dly, The elastic force of the saturated mixture of steam is equal to the elastic force of the gas in addition to the maximum tension of the steam at that temperature, and consequently the quantity of steam which the gas contains is equal to that produced at the same temperature in vacuum. Thus steam is given off when in contact with gas as in vacuum, the gas merely presenting a mechanical obstacle in retarding the vaporization, and the mixture of the gas and steam will possess all the characters of a permanent gas.

53. *Hygrometry.*—The hygrometrical state of the air is that proportion of the vapour of water to be found in the atmosphere, in comparison with that maximum quantity which it should contain when saturated; or the comparison between the tension of the vapour suspended in the air and its maximum tension corresponding to that temperature.

The two methods generally employed for determining the hygrometrical state of the air are, first, the ascertaining the decrease of temperature which the air undergoes when saturated; secondly, the employing Saussure's hygrometer.

54. The first method consists in pouring water into a silver vessel, and then successively reducing its temperature by means of iced water, until there is just a deposition of vapour on the surface of the vessel; the corresponding temperature is that to which the air should be reduced, to bring it to a state of saturation.

The tables give the maximum tension of the vapour at that temperature, and this tension is that of the vapour suspended in the atmosphere. Daniel's hygrometer may also be used for this purpose.

55. We shall obtain indications from Saussure's hygrometer, by which we can easily deduce the hygrometrical state of the air from the following table:—

Digitized by Google

TABLE OF THE ELASTIC FORCE OF VAPOUR, ANSWERING TO THE DEGREES OF THE HYGROMETER, AT THE TEMPERATURE OF 10° CENTIGRADE, EXPRESSED IN HUNDREDTHS OF THE TENSION AT SATURATION.

Tension of Vapour.	Corresponding Degrees of the Hygrometer.	Tension of Vapour.	Corresponding Degrees of the Hygrometer.	Degrees of Hygro-meter.	Corresponding Tension of Vapour.	Degrees of Hygro-meter.	Corresponding Tension of Vapour.
0°	0.00	51°	72.94	0	0.00	51	28.58
1	2.19	52	73.68	1	0.45	52	29.38
2	4.37	53	74.41	2	0.90	53	30.17
3	6.56	54	75.14	3	1.35	54	30.97
4	8.75	55	75.87	4	1.80	55	31.76
5	10.94	56	76.54	5	2.25	56	32.66
6	12.93	57	77.21	6	2.71	57	33.57
7	14.92	58	77.88	7	3.18	58	34.47
8	16.92	59	78.55	8	3.64	59	35.37
9	18.91	60	79.22	9	4.10	60	36.28
10	20.91	61	79.84	10	4.57	61	37.31
11	22.81	62	80.46	11	5 05	62	38.34
12	24.71	63	81.08	12	5.52	63	39.36
13	26.61	64	81.70	13	6.00	64	40.39
14	28.51	65	82.32	14	6.48	65	41.42
15	30.41	66	82.90	15	6.96	66	42.58
16	32.08	67	83.48	16	7.46	67	43.73
17	33.76	68	84.06	17	7.95	68	44.49
18	35.43	69	84.64	18	8.45	69	46.04
19	37.11	70	85.22	19	8.95	70	47.19
20	38.78	71	85.77	20	9.45	71	48.51
21	40.27	72	86.31	21	9.97	72	49.82
22	41.76	73	86.86	22	10.49	73	51.14
23	43.26	74	87.41	23	11.01	74	52.45
24	44.75	75	87.95	24	11.53	75	53.76
25	46.24	76	88.47	25	12.05	76	55.25
26	47.55	77	88.99	26	12.59	77	56.74
27	48.86	78	89.51	27	13.14	78	58.24
28	50.18	79	90.03	28	13.69	79	59.73
29	51.49	80	90.55	29	14.23	80	61.22
30	52.81	81	91.05	30	14.78	81	62.89
31	53.96	82	91.55	31	15.36	82	64.57
32	55.11	83	92.05	32	15.94	83	66.24
33	56.27	84	92.54	33	16.52	84	67.92
34	57.42	85	93.04	34	17.10	85	69.59
35	58.58	86	93.52	35	17.68	86	71.49
36	59.61	87	94.00	36	18.30	87	73.39
37	60.64	88	94.48	37	18.92	88	75.29
38	61.66	89	94.95	38	19.54	89	77.19
39	62.69	90	95.43	39	20.16	90	79.09
40	63.72	91	95.90	40	20.78	91	81.09
41	64.63	92	96.36	41	21.45	92	83.08
42	65.53	93	96.82	42	22.12	93	85.08
43	66.43	94	97.29	43	22.79	94	87.07
44	67.34	95	97.75	44	23.46	95	89.06
45	68.24	96	98.20	45	24.13	96	91.25
46	69.03	97	98.69	46	24.86	97	93.44
47	69.83	98	99.10	47	25.59	98	95.63
48	70.62	99	99.55	48	26.32	99	97.81
49	71.42	100	100.00	49	27.06	100	100.00
50	72.21			50	27.79		

Digitized by Google

SECT. VII. SPECIFIC HEAT OF SUBSTANCES.

56. In calling the *unit of heat* the quantity necessary to heat 1k. of water from 1°, the *specific heat* of a substance is the number of units necessary to heat 1k. of that substance from 1°.

The following table gives the specific heat of several substances; it is the result of the labours of M. Regnault, who in these experiments has employed alloys, which he has perfected, so as to render his system superior to all other methods heretofore in use.

SPECIFIC HEAT, ACCORDING TO M. REGNAULT.

Iron	0.11379
Zinc	0.09555
Copper	0.09515
Silver	0.05701
Arsenic	0.08140
Lead	0.03140
Bismuth	0.03084
Antimony	0.05077
Indian tin	0.05623
English tin	0.05695
Nickel	0.10863
Cobalt	0.10696
Platinum, rolled	0.03243
——— spongious	0.03293
Palladium	0.05927
Gold	0.03244
Sulphur	0.20259
Steel Haussmann	0.11848
Fine metal	0.12728
White cast iron of Bourg	0.12983
Charcoal	0.24111
Manganese, highly carburetted	0.14411
Mercury	0.03332
Alloy, 1 atom of lead, and 1 atom of tin	0.04073
Do., 1 atom lead, 2 atoms tin	0.04506
Do., 1 atom lead, 1 atom antimony	0.03880
Do., 1 atom bismuth, 1 atom tin	0.04000
Do., 1 atom bismuth, 2 atoms tin	0.04504
Do., 1 atom bismuth, 2 atoms tin, 1 antimony	0.04621
Alloy, 1 atom bismuth, 2 atoms tin, 1 atom antimony, 2 atoms zinc	0.05657
Do., 1 atom lead, 2 atoms tin, 1 atom bismuth	0.04476
Do., 1 atom lead, 2 atoms tin, 2 atoms bismuth	0.06082
Do., 1 atom mercury, 1 atom tin	0.07294
Do., 1 atom mercury, 2 atoms tin	0.06591
Do., 1 atom mercury, 1 atom lead	0.03827
Protoxide of lead, in powder	0.05118
——————— cast	0.05089
Protoxide of manganese	0.15701
Oxide of copper	0.14201
——— nickel	0.16234
Magnesia	0.24394
Oxide of zinc	0.12480
Peroxide of iron (oligistic iron)	0.16695
Colcothar, slightly calcined	0.17569
——— calcined second time	0.17167
——— strongly calcined	0.16921
——— do., second time	0.16707
Arseniac acid	0.12786
Oxide of chrome	0.17960
——— bismuth	0.06053
——— antimony	0.09009
Aluminum (*corindon*, a kind of spar)	0.19762
Sapphire	0.21732
Stannic acid	0.09326
Artificial stannic acid	0.17164
Stannic acid (rutile)	0.17032

Digitized by Google

Antimonic acid	0.09535
Tunstenic acid	0.07983
Molybdic acid	0.13240
Silicic acid	0.19132
Boracic acid	0.23743
Magnetic oxide of iron	0.16780
Proto-sulphate of iron	0.13570
Sulphate of nickel	0.12813
Sulphate of zinc	0.12303
Sulphate of lead	0.05086
Sulphate of mercury	0.05117
Proto-sulphate of tin	0.08365
Sulphate of antimony	0.08403
Sulphate of bismuth	0.06002
Bi-sulphate of iron	0.13009
Bi-sulphate of tin	0.11932
Sulphate of copper	0.12118
——— silver	0.07460
Magnetic pyrites	0.16023
Chloride of sodium	0.21401
——— potassium	0.17295
Proto-chloride of mercury	0.05205
——— copper	0.13827
Chloride of silver	0.09109
——— barium	0.08957
——— strontium	0.11990
——— calcium	0.16420
——— magnesium	0.19460
——— lead	0.06641
Proto-chloride of mercury	0.06889
Chloride of zinc	0.13618
Perchloride of tin	0.10161
Chloride of manganese	0.14255
——— tin	0.14759
Fluoride of calcium	0.21492
Nitrate of potash	0.23875
——— soda	0.27821
——— silver	0.14352
——— barytes	0.15228
Chloride of potash	0.20956
Phosphate of potash	0.19102
Phosphate of soda	0.22833
——— lead	0.08208
——— lead	0.07982
Arseniate of potash	0.15631
——— lead	0.07280
Sulphate of potash	0.19010
——— soda	0.23115
——— barytes	0.11285
——— strontium	0.14279
——— lead	0.08723
——— lime	0.19656
——— magnesia	0.22159
Chromate of potash	0.18505
Bi-chromate of potash	0.18937
Borate of potash	0.21975
——— soda	0.23823
——— lead	0.11409
——— potash	0.20478
——— soda	0.25709
——— lead	0.09046
Carbonate of potash	0.21623
——— soda	0.27275
——— lime (*Iceland spar*)	0.20858
Arragonite	0.20850
Grey saccharine marble	0.20989
White chalk	0.21485
Carbonate of barytes	0.11038
——— strontium	0.14483
——— iron	0.19345
——— lead	0.08596
Dolomite	0.21743
Ivory-black	0.26085
Charcoal	0.24150
Coke from cannel coal	0.20307
——— common coal	0.20085
Anthracite coal from Wales	0.20172
——— of Philadelphia	0.20100
Graphite, natural (plumbago)	0.20187
Do., from smelting furnace	0.49702
Do., from gas retorts	0.20360
Diamond	0.14687

Digitized by Google

To the above we add some others which may be found useful in practice.

Quick lime	0.2169	Laplace and Lavoisier.
Olive oil	0.3096	
Sulphuric acid (density 1.87)	0.3346	
Nitric acid (density 1.30)	0.6614	
Vinegar	0.920	Dalton.
Hydrochloric acid (density 53)	0.600	Ditto.
Alcohol (density 0.81)	0.700	Ditto.
——— (density 0.793)	0.622	Ditto.
Sulphuric ether (density 0.76)	0.660	Ditto.
——————— (density 0.715)	0.520	Despretz.
Spirits of turpentine (density 0.872)	0.472	Ditto.
Pine wood	0.650	Mayer.
Oak	0.570	Ditto.
Pear tree	0.500	Ditto.
Flint glass	0.190	Dalton.
Chloride of sodium	0.230	Ditto.
Iron from 0 to 100	0.1098	Petit and Dulong.
Iron from 0 to 200	0.1150	Ditto.
Iron from 0 to 300	0.1218	Ditto.
Iron from 0 to 350	0.1255	Ditto.

57. The specific heat of substances increases with the temperature, particularly at that temperature at which they commence to soften; it changes also with the state of coherence of the particles; and is diminished as this aggregation is increased. However, M. Regnault has discovered, from the series of experiments of which we have given the results, 1st, that for the metals, the specific heat is in inverse ratio of their atomic weight; 2ndly, that it is the same for those substances where the atomic composition and chemical components are similar; and the specific heat of an alloy is obviously the mean of that of the metals forming the alloy.

58. *Specific heat of gas.*—The determination of the specific heat of gas, presents more difficulties than that of solids or liquids, not alone that it is in itself inconsiderable, but also inasmuch as it may be examined under two different conditions; 1st. When the pressure is constant, and that the gas dilates in heating. 2ndly. When the volume is invariable, and that the elastic force increases with the temperature.

59. *Specific heat of gas under a given pressure.*—When the gases are allowed to expand freely by an increase of temperature, and under an invariable pressure, the specific heats of the simple gases are similar, but are different for the mixed gases.

Digitized by Google

The following table includes the specific heats of the principal gases compared with water and air, from the experiments of MM. Laroche and Berard.

SPECIFIC HEATS, OF DIFFERENT GASES UNDER A GIVEN PRESSURE.

Gases.	Calorific capacity of air as unity.		Calorific capacity of water as unity.
	Equal Volumes.	Equal Weights.	
Atmospheric air	1.0000	1.0000	0.2669
Hydrogen	0.9033	12.5401	3.2936
Carbonic acid	1.2583	0.8280	0.2210
Oxygen	0.9765	0.8848	0.2361
Azote	1.0000	1.0318	0.2754
Oxide of azote	1.3503	0.8878	0.2369
Carburetted hydrogen	1.0530	1.5763	0.4207
Carbonic oxide	1.0340	1.0805	0.2884
Vapour of water	1.9600	3.1360	0.8470

60. The specific heat of gas is inversely as the pressure. According to M. Suerman, the specific heat of air is 0.2868 and 0.3136 for the respective pressures $0^{m}.691$ and $0^{m}.319$.

According to M. Gay-Lussac, it increases with the temperature, but following an unknown law.

61. *Specific heat of gas of a given volume.*—When we heat a gas without allowing it to expand, at equal volumes, the specific heats of the simple gases are equal, but are less than when under a given pressure.

62. In the following table we give a comparison of these two specific heats of certain gases, and the specific heat of a given volume compared with that of air.

	Specific heat at a given pressure and volume.	Specific heat at a given volume, that of air being unity.
Atmospheric air	1.421	1.000
Oxygen	1.415	1.000
Hydrogen	1.407	1.000
Carbonic acid	1.338	1.249
Carbonic oxide	1.427	1.000
Oxide of azote	1.343	1.227
Olefiant gas	1.240	1.754

Digitized by Google

SECT. VIII. CHANGE OF CONDITION OF SUBSTANCES.

MELTING POINTS OF DIFFERENT SUBSTANCES.

Substances.	Degrees of Pyrometer.	Degrees of Centigrade.	Substances.	Degrees of Pyrometer.	Degrees of Centigrade.
Mercury	......	−39.0	Alloy of 1 tin, 1 bismuth	......	141.2
Spirits of turpentine	......	−10	Ditto 3 tin, 2 lead	......	167.7
Ice	......	0	Ditto 2 tin, 1 bismuth	......	167.7
Tallow	......	33.33	Ditto 8 tin, 1 bismuth	......	200
Acetic acid	......	45	Tin	......	210
Spermaceti	......	49	Bismuth	......	256
Stearine	......	40 to 43	Lead	......	260
Margaric acid	......	55 to 60	Zinc	......	360
Unbleached bees-wax	......	61	Antimony	......	432
Bees-wax, bleached	......	68	Copper	27	......
Stearic acid	......	70	Gold	32	......
Phosphorus	......	43	Cobalt	130	......
Potassium	......	58	Steel	130	......
Sodium	......	90	Iron	130	......
Alloy of 5 lead, 3 tin, 8 bismuth	......	100	Nickel	160	......
			Manganese	160	......
Alloy of 2 lead, 3 tin, 5 bismuth	......	100	Columbium	170	......
			Molybdenum	170	......
Iodine	......	107	Chrome	170	......
Sulphur	......	109	Tungsten	170	......
Alloy of 5 bismuth, 1 lead, 4 tin	......	118.9	Pure silver	......	999
			Silver, mixed with $\frac{1}{10}$ gold	......	1048

63. The solids in passing into the liquid state, absorb a certain quantity of heat, essential to their existence under the liquid form, and which is disengaged on solidifying. The following table gives the quantity of heat absorbed by 1^k of different substances in passing into the liquid state.

	Fusible Temperature.	Unity of Heat absorbed.
Ice	0	75.
Spermaceti	56	82.22
Bees-wax	60	97.22
Tin	219	277.77

Water, bismuth, and cast iron increase their volume on solidifying.

64. The ebullition of a liquid takes place when the elastic force of the steam produced by the liquid in vacuum at that temperature, balances the pressure exerted on it. Thus we lower the boiling point of a liquid in diminishing the pressure, and on

Digitized by Google

an increase of pressure, we also increase its point of ebullition. In a perfectly close vessel, of sufficient strength, the boiling of a liquid is imperceptible, notwithstanding its high temperature, this effect is caused by the increasing pressure of the steam acting on its surface.

65. Under similar circumstances, the boiling point of water is increased in a glass vessel from 1° to $1\frac{1}{2}$° above that in a metal one. In glass, the boiling of certain liquids is intermittent, notwithstanding the continued action of the fire; these sudden and brisk movements which accompany the production of the steam, are frequently a cause of the bursting of the vessel; this may be avoided by throwing in some metallic filings.

Liquids evaporate slowly when poured on an incandescent metal, much more so than if the metal was of a temperature below that of a dull red heat; in the former case it would seem that the liquid is not in contact with the metal, and that the heat is not received by direct communication, and that the radiated heat absorbed is but trifling.

BOILING POINT OF DIFFERENT LIQUIDS UNDER THE ORDINARY PRESSURE.

Sulphuric ether	37°.8
Sulphuret of carbon	47 .0
Alcohol	78 .4
Saturated solution of sulphate of soda	100 .7
Solution of acetate of lead	102 .0
——— chloride of sodium	106 .9
——— chlorhydrate of ammonia	114 .4
——— nitre	115 .6
——— tartar	116 .7
——— nitrate of ammonia	125 .3
——— subcarbonate of potash	140 .0
Spirits of turpentine	157 .0
Phosphorus	290 .0
Sulphur	299 .0
Sulphuric acid	310 .0
Linseed oil	316 .0
Mercury	360 .0

66. Liquids in passing into the state of vapour absorb a certain quantity of heat which remains latent in the steam, but is dismissed on its condensation.

Digitized by Google

LATENT HEAT OF STEAM ACCORDING TO M. DESPRETZ.

Substances.	Total heat from 0°.	Latent heat.	Total heat in water.	Density in comparison to that of air at the same temperature.	Density of steam at the boiling point in comparison to air at 0°.
Water	631	531	631	0.623	0.454
Alcohol . . .	410.7	331.9	255	1.613	1.258
Sulphuric ether . .	210	174.5	109.3	2.586	2.280
Spirits of turpentine .	323	166.2	149.2	5.013	3.207

67. Count Rumford gives the heat of vaporization (latent heat) of one kil. of water as 557°; Dulong, 543°; Clément and Desormes, 550°; Southern, 530; Watt, 527.

68. According to Clément and Desormes, the total quantity of heat necessary for warming and subsequently converting into steam 1 kil. of water from 0° to any temperature, is equal to 650 units of heat. Thus the caloric of vaporization diminishes as the temperature of vaporisation is increased; it will be 550 at 100°, and null 650°; but the total quantity of heat comprised in the steam will be invariable; that is to say, if we condense 1 kil. of steam at any temperature, so as to obtain water at 0°, it will always dismiss the same quantity of heat. On the contrary, according to M. Southern, the caloric of vaporization is constant, and consequently the total quantity of heat comprised in the steam increases with the temperature. Neither of these results is sustained by a sufficient number of experiments so as to be rece ied with entire confidence.

69. According to M. de Pambour, the law of Clément is alone admissible. Indeed it will follow from it, that if we dilate or compress saturated steam in a vessel without absorption or loss of heat, in the first mentioned case the steam will be cooled, in the second it will be heated, and in both events it will remain saturated, without condensation. Now, it will follow from the experiments of M. de Pambour, that on examining the tension and temperature of the steam in the boiler of the locomotive, and on its leaving the cylinder, the pressure is at all times that as given in the tables at the observed temperatures. But the experiments of M. de Pambour have been made within too restricted limits of pressure, so as to receive his law unconditionally or as verified under all circumstances.

Digitized by Google

SECT. IX. SOURCES OF HEAT AND COLD.

70. The sources of heat are, solar heat, the central terrestrial heat, pressure, percussion, friction, the change of condition of bodies, and chemical action. We shall not speak of solar heat, or of the central heat of the earth, as being foreign to our subject. We shall also pass unnoticed that derived from pressure, percussion, or friction, as the effects resulting from these causes are unimportant. We have already spoken of the effects produced by the change of condition of substances. As to chemical action, that derived from combustion being alone employed in the production of heat, to the consideration of which we shall devote the second chapter of this work.

71. The sources of cold consist in the dilatation of gases, in the liquefaction of solids by chemical action, and in spontaneous vaporization. We shall limit ourselves to giving, in the table annexed, the effects produced by different frigorific mixtures.

TABLE OF FRIGORIFIC MIXTURES.

Mixtures of Water and Salts.

	Parts.		Cold produced.
Water	16	from +10° to −12°	22°
Nitre	5		
Muriate of ammonia	5		
Water	16	from +10 to −16	26
Muriate of ammonia	5		
Nitre	5		
Sulphate of soda	8		
Water	1	from +10 to −16	26
Nitrate of ammonia	1		
Water	1	from +10 to −19	29
Nitrate of ammonia	1		
Subcarbonate of soda	1		
Water	4		15
Chloride of potassium	57		
Hydrochlorate of ammonia	32		
Nitrate of potash	20		

Mixtures of Ice and Salts.

Snow or pounded ice	2		20
Salt	1		

Digitized by Google

	Parts.		Cold produced.
Snow or pounded ice	5		24°
Sea salt	2		
Sal ammoniac	1		
Snow or pounded ice	24		28
Sea salt	10		
Sal ammoniac	5		
Nitre	5		
Snow or pounded ice	12		31
Sea salt	5		
Nitrate of ammonia	5		

Mixtures of Acids and Salts.

	Parts.		Cold produced.
Sulphate of soda	3	from +10° to −19°	29
Diluted nitric acid	2		
Sulphate of soda	6	from +10 to −23	33
Sal ammoniac	4		
Nitre	2		
Diluted nitric acid	4		
Sulphate of soda	6	from +10 to −26	36
Nitrate of ammonia	5		
Diluted nitric acid	4		
Phosphate of soda	9	from +10 to −29	39
Diluted nitric acid	4		
Sulphate of soda	20	from +10 to −8.15	18.15
Sulphuric acid at 36°	16		
Sulphate of soda	22	from +10 to −8	18
Residuum of ether at 33°	17		
Sulphate of soda	8	from +10 to −17	27
Chlorhydric acid	5		

SECT. X. DENSITY.

72. For solids and liquids the density is in proportion to the weight of the substance to that of an equal volume of water at 4°. For these substances, the weight, the volume, and density, are united by the equation

$$P = Vd,$$

in which the unity of the weight is equal to the weight of water comprised in the unity of volume.

Digitized by Google

TABLE OF DENSITY OF A CERTAIN NUMBER OF SOLIDS AND LIQUIDS.

Platina rolled	22.0690	Alabaster	1.8740
——— wire-drawn	21.0417	Anthracite	1.8000
——— hammered	20.3366	Alum	1.7200
——— purified	19.5000	Coal, compact	1.3292
Gold forged (or hammered)	19.3617	Jet	1.2590
—— cast	19.2581	Yellow amber	1.0780
Mercury at 0°	13.5980	Melting ice	0.9300
Lead, cast	11.3523	Potassium	0.8651
Silver, cast	10.4743	Beech	0.8520
Bismuth, cast	9.8220	Ash	0.8450
Copper wire	8.8785	Yew	0.8070
Copper, cast	8.7880	Elm	0.8000
Arsenic	8.3080	Apple-tree	0.7330
Nickel, cast	8.2790	Orange-tree	0.7050
Steel, soft	7.8163	Fir, yellow	0.6570
Cobalt, cast	7.8119	Lime-tree	0.6040
Iron, in bars	7.7880	Cypress	0.5980
Tin, cast	7.2914	Cedar	0.5610
Iron, cast	7.2070	Poplar, white Spanish	0.5290
Zinc, cast	6.8610	Sassafras	0.4820
Antimony, cast	6.7120	Poplar, common	0.3830
Spar, heavy	4.4300	Cork	0.2400
Flint glass	3.3293	Sulphuric acid	1.8409
Fluor spar	3.1911	Nitrous acid	1.550
Tourmaline (green)	3.1555	Water of the Dead Sea	1.2403
Asbestos, inflexible	2.9958	Nitric acid	1.2175
Marble of Paros (or Parian)	2.8376	Sea water	1.0263
Carbonate of lime, crystallized	2.7182	Milk	1.03
Rock crystal, pure	2.6530	Distilled water	1.0000
Quartz, agate	2.6150	Wine, Bordeaux	0.9993
Felspar, transparent	2.5644	——— Burgundy	0.9915
Glass of St. Gobain	2.4882	Oil, olive	0.9153
Porcelain, China	2.3847	Ether, chlorhydric	0.874
Sulphate of lime, crystallized	2.3117	Essential oil of turpentine	0.8697
Porcelain of Sevres	2.1457	Liquid bitumen, naphtha	0.8475
Sulphur, native	2.0332	Alcohol, pure (or highly rectified)	0.792
Ivory	1.9170	Ether, sulphuric	0.7155

Digitized by Google

73. For the gases, the unit of density is the density of air, and we have also the formula $P=Vd$; but for the weight, the volume of air is taken as unit.

TABLE OF DENSITY OF THE PRINCIPAL GASES.

Gases.	Density.	Weight in grammes of a litre of gas at 0° and under a pressure of $0^m.76$.
Air	1.000	1.2991
Hydriodic acid gas	4.443	6.7719
Fluosilicic acid gas	3.5735	4.6423
Chloro-carbonic acid gas		4.4156
Chlorine	2.470	3.2088
Euchlorine		3.0081
Fluoboric acid	2.3709	3.0800
Sulphurous acid	2.1204	2.8489
Chloro-cyanic acid		
Cyanogen	1.8064	2.3467
Protoxide of azote	1.5204	1.9752
Carbonic acid	1.524	1.9805
Hydrochloric acid	1.2474	1.6205
Hydrosulphuric acid	1.1912	1.5475
Oxygen	1.1036	1.4323
Bi-oxide of azote	1.0388	1.3495
Olefiant gas	0.978	1.2752
Azote	0.976	1.2675
Carbonic oxide	0.9569	1.2451
Phosphuretted hydrogen	0.87	
Ammonia	0.5967	0.7752
Carburetted hydrogen	0.555	0.7270
Arsenical hydrogen	0.529	
Hydrogen	0.0688	0.0894

Digitized by Google

CHAPTER II.

COMBUSTION AND COMBUSTIBLES.

SECT. I. OF COMBUSTION IN GENERAL.

74. Combustion consists solely in the fact of the combination of substances with oxygen; this phenomenon is often accompanied with heat and light, but not invariably.

75. Oxygen is a gaseous body, colourless, but heavy, elastic, and possessing all the properties of atmospheric air, of which it forms one of the elements. Air is composed of seventy-nine parts azote, and twenty-one of oxygen. Azote being inefficient in the phenomena of combustion; we shall therefore not describe its properties, the knowledge of which is unnecessary for the subject in which we are engaged.

76. Oxygen possesses the remarkable property of combining with all simple substances, and with many of the compounds. All these bodies enter into the class of combustibles.

77. The affinity of different combustibles for oxygen is very variable; some absorb it at the ordinary temperature, others require a temperature more or less elevated, and others again are incapable of combining with oxygen except when freed from the liquid or solid form. In this evanescent state it is called incipient gas.

78. Oxygen may be brought in contact with combustibles, under a variety of forms; as it exists not only in the air, but in many other substances. We can produce combustion of bodies by the medium of air, by pure oxygen or mixed with other gases, and also by the combination of solids or liquids containing oxygen. Under all circumstances, there is a combination of a combustible substance with oxgyen. When combustion of a body takes place in air, the latter supplies the necessary oxygen; if the mass of air is small in proportion to that of the combustible, it is soon exhausted, and ceases to support the combustion; to produce the phenomenon, combustion, it is thus necessary to have a continued supply of atmospheric air. When a metal is dissolved in acid, the metal undergoes an actual combustion, and it is the acid or water which, in decomposing, furnishes the necessary oxygen. In the explosion of gunpowder, the combustible matter, that is, the sulphur and charcoal, also enter into combustion, the oxygen for which is supplied by the saltpetre.

79. It will evidently follow from what we have stated, that the product of combustion should be heavier than the combustible, by the addition of all the oxygen absorbed. But the product of combustion may be a solid or a gas. In the first case,

Digitized by Google

the residue of combustion is comprised in the product, which is easily recognised by the increased weight. In the second, the product is disengaged in proportion as it is formed, and the residue merely consists of incombustible substances which existed in the material consumed. It is thus that, in burning lead in an earthen or cast-iron vessel, we obtain for product a grayish substance considerably heavier than the original material; and on the contrary, in the combustion of wood or coal, the residue is merely the extraneous matter which the combustible contained. It is therefore necessary to distinguish between the product and the residue. The product is a combination of oxygen and the combustible substance, the weight of which always exceeds that of the latter, and is deposited with the residue, or is disengaged according as it may be a solid or a gas.

80. We have already said that heat and light usually accompany combustion. It would seem that in general light is not visible until the temperature of the substance has at least attained 500°. At that temperature the light is of a dull red, nearly imperceptible; but in proportion as the temperature increases, the light acquires a greater brilliancy, becomes of a cherry-red colour, and at a very high temperature is almost completely white.

81. When a combustible is a solid, and continues such at whatever temperature it may be exposed to during the process of combustion, this phenomenon only takes place at the surface of the combustible, and that surface alone is luminous. The surrounding atmosphere, though exposed to a very high temperature, is not luminous, inasmuch as a gas is insusceptible of so becoming by the imparted heat, however intense it may be; it is only when it is in itself a combustible, and when inflamed, that it becomes luminous. Thus, coal freed from other combustible material, is only luminous at the surface. The flame in general proceeding from it, at least in the commencement of its combustion, originates from a certain quantity of hydrogen which it always contains, when not previously submitted to rather a high temperature, and moreover to the water absorbed by the coal in its exposure to the atmosphere, and which is decomposed at an elevated temperature.

82. But if the combustible is capable of passing off in vapour at a lower temperature than that developed in combustion, then the vapour itself will enter into combustion. The point of combustion will be placed above the combustible, as the vapour at that elevated temperature is lighter than air. The form of this luminous space will at the same time depend on the form and velocity of the current of vapour and air. If the combustible, in place of passing off in vapour, is decomposed and disengages an inflammable gas, as for example, from wood, coal, and oil, the same phenomena will take place on the burning of these gases.

Digitized by Google

83. The point of combustion of a gas is its exterior surface. An experiment will easily prove that the flame is readily caused by the burning of the gas disengaged from the combustible. To this effect, if we extinguish a candle in such a manner as still to preserve a part of the wick ignited, it will give off a column of thick smoke, accompanied with a heavy smell; in bringing this smoke in contact with a lighted substance, it will inflame, and combustion will be quickly communicated to the wick from above downwards, the flame of the candle will become as at first, and the smoke cease. This smoke may also be burned at a certain distance from the wick, and prevent the combustion from reaching it; for this purpose, it is merely necessary to place a tissue of wire-gauze a little above the wick, and to set fire to the gas which passes through; the wire-gauze will intercept the flame, and we thus obtain a flame above and smoke underneath. But to produce this effect it is necessary that the apertures in the wire-gauze should be in proportion smaller, as the gas which we wish to obstruct is the more inflammable. This singular property of wire-gauze has been attributed by Davy to the effect of its cooling the flame. But M. Libri considers it much more probable as being the result of an actual repulsion taking place between the heated substances.

84. The flame is luminous only at its surface, as it is there alone that the inflammable gas is in contact with the air; moreover, this is of easy verification by placing a metallic tissue across the flame of a candle: this tissue will intercept the flame, and viewing it above the wire-gauze, the centre of the flame will be seen quite black.

85. The length of the flame is the distance passed over by a transverse section of the gas, whilst the combustion is passing from the circumference to the centre of this section. It will evidently be so much the longer as the current of air is slower. We can ascertain the influence of the velocity of the current of air on the length of the flame by means of a lamp with a chimney; if we increase the length of the chimney with a paper cylinder of the same diameter, which will also increase the current of air, the flame will diminish; if we decrease its length or diminish the opening, which will likewise decrease the current, the flame will lengthen. From this there result very important consequences in the arts; we can at will diminish or increase the flame of a fire by increasing or decreasing the draught.

86. When inflammable gas is evolved from a large extent of ignited surface, it is never perfectly consumed, at least if some means are not employed to increase the current of air, as the central part of the column of gas will be too much reduced in temperature when it has arrived at that position so as to come in contact with the atmosphere. For this reason, until the invention by Argand, we could only use in

Digitized by Google

lamps wicks of very small diameter, and consequently could obtain a flame of but weak intensity. But by employing the single or double circular burner, and with a chimney, by which the air is brought in contact with the wick externally and internally, and from which the velocity of the current is accelerated by the draught of the chimney, we by these means obtain any wished-for intensity of flame, a combustion without smoke, and a useful effect of oil much greater than with the old apparatus.

87. The flame naturally assumes a vertical direction from below upwards, caused by the elevated temperature of the gas, before, during, and after combustion; but this direction is modified by that of the current of air; the flame may be inclined in any manner whatsoever to the horizon; it may be even directed horizontally, or from above downwards.

88. The temperature produced by the combustion of gaseous bodies is considerably more elevated than that of solids; this we might infer from the colour and brilliancy of the flame, which cannot be obtained from solids unless the combustion is forcibly supplied by a current of air, or by pure oxygen. We can easily convince ourselves of this fact by immersing in the flame a solid of small dimensions: it will acquire a brilliancy such as could not be produced except at an extremely elevated temperature.

89. To ignite the gases, they require a more or less elevated temperature, depending on their peculiar properties. Some may be inflamed in the air at the ordinary temperature; such as the gas formerly known under the name of perphosphurated hydrogen. Others require a higher temperature than that of cherry-red; in the latter are included the greater part of the gases and vapours evolved by the combustibles employed in heating and lighting; every one is aware that a body at a heat of cherry-red cannot inflame the smoke of a lamp, a candle, wood, &c.

90. When the combustion is perfect, the quantity of heat evolved, as we shall hereafter see, is at all times the same for an equal quantity of the same combustible, whatever may be the circumstances of the combustion; it is also similar when the combustion is produced by air, under a greater or less pressure than that of the atmosphere, or when the quantity of oxygen in the atmosphere is increased or diminished, and even when the combustion takes place in pure oxygen. But this will change with the nature of the combustible. On the contrary, with a similar combustible, and the same consumption in an equal time, light will be influenced by the circumstances which accompany the combustion, and more particularly by the velocity of the current of air.

91. To obtain the greatest brilliancy from an inflammable gas, it is necessary

Digitized by Google

that it be of a high temperature, and consequently that the current of air supporting the combustion should have a considerable velocity; but in proportion as it increases in brilliancy, the size of the flame is lessened, and as this diminution is greater than the increased brilliancy of each particle, its illuminating power is reduced. There is a certain velocity of the current of air which in each particular circumstance will give a maximum of illuminating effect, and that is, where the quantity of air supplied to the flame is merely sufficient to produce a perfect combustion.

92. To produce a very brilliant flame, it is necessary that it should contain a solid under one form or another; that is, either a solid in a state of permanence, or that the gas has deposed it before burning, or otherwise that the residue of the combustion is a solid. All combustion of gases, not fulfilling one or other of these conditions, will take place with a feeble light. Thus the combustion of pure hydrogen or sulphur gives a flame of little brilliancy, as the product of the combustion of hydrogen is the vapour of water, and that of sulphur gaseous sulphuric acid. But the flames of phosphorus, arsenic, and carburetted hydrogen, are particularly brilliant; as the products of the combustion of the first two are solids, and that of carburetted hydrogen is preceded by a deposit of coal.

The necessity of the existence of a solid in the flame in order that it may be brilliant, is caused, inasmuch as gases are not luminous excepting at a much more elevated temperature than solids.

93. We shall not for the present enter further into the subject of combustion; but in speaking separately of the different combustibles employed in the arts, we shall examine the particular circumstances their combustion presents, as well as their residue.

SECT. II.—OF COMBUSTIBLES IN GENERAL, AND THE METHODS EMPLOYED IN DETERMINING THEIR HEATING AND RADIATING POWER.

94. Combustibles are very numerous, for this important class comprises, not only all the simple substances, but likewise a great many compounds. Nevertheless, those which are used in the arts for the generation of heat are restricted in number, as to be there employed they must fulfil many important conditions, which thereby excludes a large class.

95. Firstly, They should burn with facility in atmospheric air, and the heat disengaged by the combustion should be sufficient for its maintenance; or, in other words, the heat evolved by the combustion should exceed that which is necessary for its production. Sulphur, coal, hydrogen, and phosphorus, fulfil these conditions; but

Digitized by Google

iron and lead, though very combustible, must be here excluded, for when these metals are in ignition, if we withdraw them from the fire, where it is necessary they should be placed, combustion will cease. This is owing, probably, to the burned substance which forms on them being solid, and depositing a crust round the metal that protects it from the action of the air; this would still seem the most probable cause, when we consider that in pure oxygen, where the combustion of iron is sustained, the temperature is sufficiently elevated to melt the oxide of iron, and cause it to run in proportion as it is formed. Be this as it may, there are many very combustible substances in which combustion will not extend itself under the ordinary circumstances, and these can be of no utility in the arts for the production of heat or light. Secondly, Combustibles should also be abundant, and obtainable at a moderate price. Thirdly, The products of the combustion should be of that nature as not to impair those bodies receiving the action of the heat, or that the gases or vapours passing into the atmosphere should not be prejudicial to animal or vegetable life.

96. Carbon and hydrogen are the only simple substances uniting these several qualities; thus, the only combustibles employed are those in which these two bodies form the principal elements.

97. The combustibles generally employed are:—

Wood.
Charcoal.
Tan.
Peat.
Peat coke.
Coal.
Coke.

98. We shall henceforward designate under the name of *calorific power* of a combustible, the number of units of heat (56) developed by a kilogram* of a substance in combustion; we have already said (90) that for the same combustible, this is an invariable quantity, whatever may be the circumstances of the combustion.

99. On some occasions the nature of the combustible, which we are enabled to employ, is restricted by the peculiarity of the conditions to be fulfilled; at other times we have only one at our disposal. But, most frequently, we are enabled to employ several. Under all circumstances, it is of importance that we should know their calorific power, in order to determine the quantity necessary to be employed to produce the effect required, as well as to calculate the dimensions of the apparatus; and in general, where we are enabled to employ different combustibles, it is from a know-

* 2.2060 lbs. avoirdupois.

Digitized by Google

ledge of their calorific power, together with their value, that we can determine which is really the most economical.

100. *Methods employed to determine the calorific power of combustibles.*—Rumford was the first natural philosopher who undertook the determination of the calorific power of combustibles; the apparatus used by him, and which is still known under the name of Rumford's calorimeter, consists of a low copper case, in the bottom of which is placed a spiral tube, communicating at one end with an inverted funnel placed under this case, and at the other, with a vertical tube rising to a certain height. In using this apparatus, the vessel is to be filled with water at a fixed temperature, and the smoke of the combustible which is burned under the funnel is made to pass through the worm or spiral tube; then, by knowing the weight of the combustible consumed, the weight of the water contained in the vessel, the increase in its temperature, and the weight of the vessel, we can deduce the quantity of heat developed by a given weight of a combustible. Let us suppose, for example, that the quantity of combustible consumed is 10 grammes, the weight of the water 10 kilograms, that of the case 1 kilogram, and the elevation of temperature 5°. As the specific heat of copper is 0.0949, the quantity of heat absorbed by the case will be equal to that absorbed by the same weight of water multiplied by 0.0949; thus, the heat evolved has raised to 5° a weight of water equal to $10^k + 1 \times 0.0949 = 10.0949$, and should be able to elevate to one degree $10.0949 \times 5 = 50.4745$ kilogrammes of water, and consequently the calorific power of the combustible would be equal to $50.47 \times \frac{1000}{10} = 5047$.

101. In using Rumford's calorimeter, independent of the correction in reference to the mass of the apparatus and to the cooling during the operation, it is necessary to attend to two other sources of error: the one relative to the quantity of heat carried off by the gas issuing from the spiral tube; the other, as to the quantity radiated by the combustible under the funnel, where the combustion takes place. These two corrections are important, and I do not think that attention has been paid to them; for the first requires, not only a knowledge of the temperature of the air on its issuing, but also that of the velocity of the current, which is rather difficult to determine; and to ascertain the second, it is necessary to know the quantity of heat which the different combustibles radiate, and to measure the extent of the cone which permits the radiation to escape. From this we may consider that in using Rumford's calorimeter, the results arrived at will be underrated.

102. There have also been a number of experiments made by Laplace and Lavoisier with the calorimeter which has received its name from these two celebrated men; the interior contained a worm or spiral tube communicating at one side with a funnel, under which the combustible was consumed, and at the other with a vertical

Digitized by Google

tube serving as a chimney. But this mode of experimenting is subject to considerable error. Hassenfratz has also made some experiments with the same apparatus, and the results obtained prove, from their great irregularity, the defects of this mode of operating.

103. M. Despretz has since conducted more accurate experiments on some substances than those heretofore made. He used Rumford's calorimeter, but so modified as to avoid the loss of heat by the radiation of the combustible, and so considerable, that the temperature of the water, at the completion of the combustion, only exceeded by 2° that of the air; by these means we may omit taking into account the loss of heat by the cooling of the vessel during the operation, or the quantity carried off by the air on issuing from the apparatus.

104. Some few years since Marcus Bull performed a number of experiments in America to determine the relative calorific power of different combustibles. An extract from his memoir will be found in "*Le Bulletin de la Société d'Encouragement*," page 80, 1827; and "*Franklin's Journal*," *May*, 1826. We here state the manner in which he carried on these experiments. His apparatus consisted of a room constructed in wood within another in an ordinary dwelling-house, so that the sides of these rooms were at equal distances: when, by the combustion in a stove of a certain quantity of charcoal, he had established a difference of 10° between the external and internal air of the smaller room, he determined the time during which this difference was maintained, by the consumption of a given weight of several combustibles. This is a very complicated method, and comprises many causes of error; we shall, however, give the results obtained, when speaking of the different classes of combustibles.

105. We also find in the papers of M. Dulong, the results of numerous experiments on the calorific power of a certain number of bodies. These numbers were obtained by means of an apparatus similar to that of Rumford's, described in the account given of the meeting of the Institute, vol. 7, by M. Gamand, formerly a pupil of the Polytechnic School; but we are ignorant as to the details of these experiments.

106. To determine with considerably more precision the calorific power of combustibles, it will be necessary to use an apparatus similar to that of Rumford's, but much larger, and so as to contain, for example, several cubic mètres of water, with a fireplace arranged like that of a steam-boiler; we may estimate the calorific power by the weight of the water evaporated, on correcting the result obtained from the cooling of the vessel, and the temperature of the heated air on its passing off. This method is much to be preferred to those which have been employed, as we

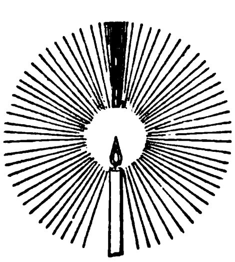
Digitized by Google

can at will prolong the experiment, and the fire being internal there is no loss of heat by radiation; also, inasmuch as we can extend our researches to the different combustibles employed in the arts, even to those which can only be consumed in large masses. But we shall hereafter see that these costly experiments are not necessary, and that we can deduce the calorific power of combustibles from their composition, when knowing that of the carbon and the hydrogen.

107. *Radiated heat.*—When a body is in combustion, the heat is dissipated in two different ways: 1stly, by the current of air spontaneously formed, whether the combustion takes place in the open atmosphere, or is carried on in a closed apparatus; 2ndly, by radiation. The current of air arises from the specific lightness which it acquires in supporting the combustion. Air, when in contact with an incandescent body, becomes heated, dilates, becoming specifically lighter than the surrounding atmosphere, and consequently should ascend; it is replaced by a fresh supply, which, in its turn, is heated, and ascends after it has supplied the combustion; thus the combustion in itself excites the current of air necessary for its support. As to the second cause of the loss of heat evolved by combustion, it originates from a general property of all heated bodies.

Hitherto, the radiating of combustible bodies has been completely disregarded, being considered of trifling effect. To prove that the quantity of heat dissipated by radiation is very inconsiderable, it has been compared to that which we experience in approaching the hand laterally or vertically to the flame of a candle; laterally, we only receive the radiated heat; vertically, that of the current of heated air. And as at equal distances, the difference of temperature is enormous, it has been inferred that the dispersion of heat by radiation is very trifling, at least when compared with that carried off by the atmosphere.

This experiment, which at first view would seem decisive, nevertheless cannot lead us to the conclusions generally received. In fact, the current of heated air passes off only in one direction, and its diameter exceeds but little that of the flame, whereas the radiation takes place on all sides. Thus, to know the relative quantities of heat dissipated by the current of air and by radiation, it is not sufficient to compare the temperature of the current to that produced by the radiation at equal distances from the flame, it will be necessary to multiply the latter by the relative extent of the sphere to that of the sector intercepted by the current of air; and moreover take into consideration a great number of other circumstances, such as the velocity of the current, the calorific capacity of the air, &c.



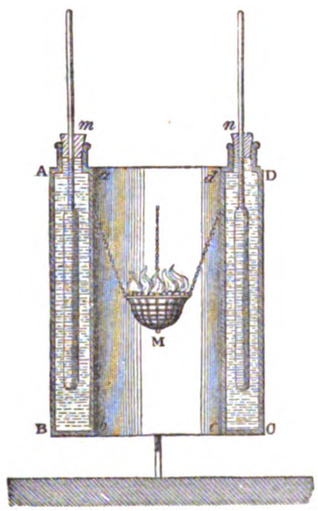
It will seem from the above that the experiment mentioned supplies no proof as

to the radiation from the flame, and still much less for that of combustibles which burn without flame.

108. It is important to determine the relative quantity of heat dissipated by radiation, as it is that alone which is turned to useful effect in our domestic fire-places; and it would be well to ascertain whether, as many authors have declared, we only thus receive the benefit of some hundredths of the heat developed by the combustible.

I have made a number of experiments on this subject with wood, charcoal, peat, peat coke, and coal; and I have obtained results very discordant from those generally received. These results shall be given when we enter into a separate examination of the different combustibles. I shall here merely describe the apparatus which I employed, and the method of observation.

Fig. 1.



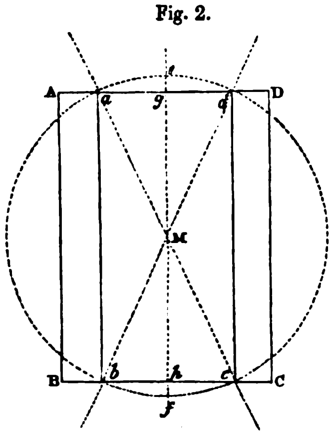
The apparatus which I made use of consisted (fig. 1) of a circular tin case, A B C D and *a b c d*; the space comprised between the two concentric cylinders, A B C D and *a b c d*, is closed above and below; in the upper part are placed the two tubular orifices *m* and *n*, intended to receive two thermometers with long reservoirs, the stems of which pass through the corks by which these orifices are closed. In the centre of the interior cylinder, which is completely open at the two extremities, is suspended a hemisphere of iron wire, intended to receive the combustible; the interior of the cylinder *a b c d* is covered with a thin coating of lamp-black, and the apparatus is supported on three feet.

To use this apparatus, we commence by filling with water the space between the two cylinders; then place the thermometers, and introduce a definite quantity of combustible in ignition into the grate M; a part of the radiated heat is received by the sides, *a b c d*, of the vessel, and enters into the water. When the combustion is terminated, we observe, by means of the thermometers, the temperature of the liquid; then, knowing the weight of the water and that of the metallic vessel, we can easily calculate the quantity of radiated heat absorbed. But to deduce the total quantity of radiated heat evolved by the combustible, it is evident that we must determine the ratio between the whole surface of the sphere, and that of the annular sector which circumscribes the cylinder *a b c d*, for the vessel has really absorbed but the rays comprised between the straight lines which unite the centre of the sphere M with the several points of the upper and lower circumference

Digitized by Google

of the interior cylinder, and all the rays in the direction of the spherical ends $a\,d$ and $b\,c$ have escaped.

Fig. 2.



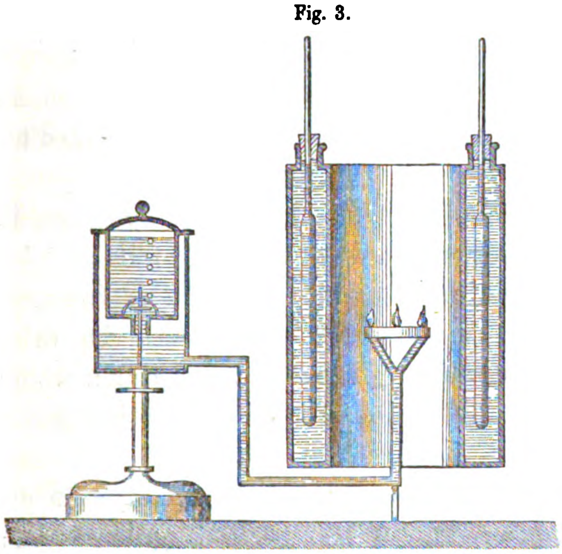
It is easy to determine this latter ratio. As we know that the portion of the surface of a sphere generated by an arc, is in proportion to its projection on the axis of rotation; consequently the absorbing surface is to the sphere as $g\,h$ is to $e\,f$ (fig. 2).

In the apparatus which I have used $a\,d = 0^{m}.20$ (nearly 8 in.) $a\,b = 0^{m}.30$ (nearly 1 ft.) from which we deduce:

$$ef = 2\,\mathrm{M}\,e = 2\,\mathrm{M}\,a = 2\sqrt{\mathrm{M}\,g^2 + a\,g^2} = 2\sqrt{(0.15)^2 + (0.10)^2} = 0.36;\ \text{and}\ a\,b = 0.30.$$

Thus the total radiation is to that absorbed :: 36 : 30 or :: 12 : 10. From which it will follow that we must multiply the quantity of heat obtained by $\frac{6}{5} = 1.20$, to have the whole quantity of heat evolved by radiation.

Fig. 3.



It is evident, that to avoid the loss of heat by the sides of the vessel, we must have recourse to Rumford's system, and place in the vessel water of a temperature as much under that of the atmosphere, as it will exceed it at the conclusion of the experiment.

109. In performing experiments on liquid combustibles, such as oil, I employed the apparatus (fig. 3), which is a reservoir of an invariable level, placed outside the apparatus, supplying seven burners arranged in a circle on a small annular tube.

SECT. III.—WOOD.

110. Wood is composed, 1stly, of a substance to which M. Payen has given the name *cellulose*, forming the solid portion of all plants; this substance, which is invariably of the same chymical composition, contains 0.444 of carbon and 0.556 of oxygen, and hydrogen in the necessary proportions to form water. 2ndly. Of an in-

Digitized by Google

crustaceous substance, the composition of which varies according to the nature of the wood, but is richer in carbon and contains a small surplus of hydrogen. The ordinary fire-wood, perfectly dry, seldom contains more than 0.02 of extraneous matter.

111. The density of wood is extremely variable, as may be seen from the following table by Brisson:

Pomegranate Tree	1.35	Cherry Tree	0.71
Lignum vitæ	1.33	Orange Tree	0.70
Box, Dutch	1.32	Quince Tree	0.70
Oak, 60 years old (the heart)	1.17	Elm (the trunk)	0.67
Medlar Tree	0.94	Walnut, French	0.67
Olive Tree	0.94	Pear Tree	0.66
Box, French	0.91	Cypress Tree, Spanish	0.64
Spanish Mulberry Tree	0.89	Lime Tree	0.60
Beech	0.85	Hazel Tree	0.60
Ash (the trunk)	0.84	Willow	0.58
Alder Tree	0.80	Thuya	0.56
Yew, Spanish	0.80	Fir Tree, male	0.55
Apple Tree	0.79	Fir Tree, female	0.49
Yew, Dutch	0.78	Poplar	0.38
Plum Tree	0.78	Poplar, white Spanish	0.52
Maple	0.75	Cork	0.24

112. Winter is the most favourable time for cutting timber; it should remain where it has been felled the succeeding summer, and should not be brought forward for consumption until autumn.

113. When we expose wood which is perfectly dry in a room without fire, in twelve months it will absorb a quantity of water equal to a tenth of its weight. Marcus Bull, to whom we are indebted for this information, performed experiments on forty-six species of wood; the results of which were all similar. In drier weather the absorption did not amount to more than 8 per cent. From this it would seem that the quantity of moisture which may be absorbed by dry wood is entirely independent of its nature or density.

Green timber contains very unequal quantities of water. From the experiments made by Marcus Bull, walnut lost by drying 37.5 in 100 parts of green wood; white oak (*quercus alba*), 41; maple, 48. Thus it appears that wood contains a greater quantity of water in proportion as its density is less. We may estimate as a mean, at 42 in 100, the quantity of water contained in green wood which has been cut four or five months, and which is employed in the forest for the making of charcoal, and merely at 20 or 25, that contained in the ordinary firewood which has been exposed to the atmosphere for eight or twelve months.

Digitized by Google

A direct analysis of charcoal wood ("*bois de charbonnage*") has given the following results:

Hygrometric water[a]	0.275
Carbon	0.375
Oxygen and Hydrogen	0.338
Ashes	0.012

114. In reference to its use as a combustible, wood is divided into two classes. The first comprises the hard and compact woods, those of which the specific gravity is most considerable; such as oak, beech, elm, and ash, &c. The second includes the white woods, soft, and light; such as pine, fir-tree, birch, aspen, and poplar, &c.

In France, firewood is classed into new ("*neuf*") wood, floated wood, and barked "*pelard*") wood. New wood is that which has been brought to the place of consumption in a wheel carriage or in a boat, and from which the bark has not been detached; floated wood is that which has been conveyed floating, in the form of a raft; and lastly, barked wood is merely oak stripped of its bark.

115. A similar weight of damp wood gives much less heat than that which is dry, 1st, as water is not combustible, it cannot evolve heat; 2dly, as this liquid absorbs a considerable quantity in passing into the form of steam. Count Rumford was the first who drew attention to the disadvantage of using damp wood.

The advantage of using dry wood is so great, that in several manufactories, such as those of fine glass and porcelain, they are not alone content that the wood received should be as dry as it can be made by exposure to the atmosphere, but it is again dried in stoves. Wood is also employed to produce the heat necessary for its desiccation; but for this purpose it would be much more beneficial to apply part of the heat wasted in the furnace. We shall hereafter speak of the distribution of the apparatus to be employed.

According to M. Héron de Villefosse, the annual production of France in firewood is 9,804,928 cordes, each $2\frac{1}{4}$ stères[b], representing a value of 84,163,646 francs. This production is nearly equal to 70,000,000 hectolitres of coal, unheaped measure.

116. *Products of combustion.*—The products of the perfect combustion of wood are solely formed of the vapour of water and carbonic acid. But when the com-

[a] The quantity of water that may be absorbed, when either in immediate contact in the liquid form, or in the state of vapour in the atmosphere.—J. T. F.

[b] A stère = a cubic mètre, or 3,531,716 cubic feet. See "Templeton's Engineers' Pocket-book, for French measures," page 2.

Digitized by Google

bustion is incomplete, smoke is disengaged, which is principally composed of water, acetic acid, empyreumatic essential oil, and of a substance resembling tar. The acetic acid is the cause of the stimulating effect of the smoke on the eyes.

Carbonic acid is a colourless gas, inodorous, much heavier than air, incombustible, and incapable of supporting combustion; it rises in the atmosphere during combustion, from the high temperature which it acquires.

117. The following table, extracted from a memoir of M. Berthier, (*Annals of Chymistry*, vol. 32,) gives the quantity of ashes produced by different woods.

The quantity of ashes produced by different woods and vegetable combustibles.

Oak	0.025	Mulberry-tree, white	0.0160
Oak bark	0.0600	Birch-tree	0.0100
Lime-tree	0.0500	Laburnum	0.0125
Mahaleb[a], or perfumed cherry-tree	0.0160	Fir-tree	0.0083
Elderberry-tree	0.0164	Wheaten straw	0.0440
Judas-tree	0.0170	Potato stalks	0.1500
Hazel-tree	0.0157		

According to M. de Saussure.

Young oak branches stripped of their bark produce	0.004	of ashes.
Their bark	0.060	
Oak trunk	0.002	
Its bark	0.060	

It is to be observed, that the quantity of ashes produced by the same wood, varies with the nature of the soil, the situation, the age, and is even different in the separate parts of the same tree. In general, the ligneous plants produce less than the herbaceous; the evergreens less than those trees which are stripped of their leaves in winter; the trunk of the tree less than its branches; the branches less than the leaves and bark, and the heart of the wood less than the sap.

118. As the cellulose and the incrustaceous substance is variable in the different species of wood, it will follow, that all wood in the same state of desiccation should not evolve exactly the same quantity of heat. But as the difference of the component parts of ordinary firewood is trivial, we may consider their calorific power as nearly similar. Moreover, this has been confirmed by the experiments of M. Berthier.

119. Rumford, after him Hassenfretz, and recently Marcus Bull, have made

[a] "Bois de Sainte-Lucie" (*cerasus mahaleb*), or perfumed cherry-tree.

Digitized by Google

considerable experiments to determine the quantity of heat evolved by the combustion of different species of wood. Rumford used the apparatus called after him; Hassenfretz used the ice calorimeter; and Marcus Bull the apparatus which we have described (104). Each experimented on equal weights of wood in the ordinary state of desiccation or previously dried.

The principal results obtained by Rumford are here given; we have changed the quantities of melted ice into units of heat.

TABLE OF THE QUANTITY OF HEAT DEVELOPED BY THE COMBUSTION OF A KILOGRAMME OF DIFFERENT SPECIES OF WOOD.

Species of Wood [a].	State when tried.	Units of Heat developed.
Lime-tree . .	Joiners' dry wood, 4 years old	3460
Ditto . . .	Highly dried in a stove	3960
Beech . . .	Joiners' dry wood, 4 years old	3375
Ditto . . .	Highly dried in a stove	3630
Elm . . .	Joiners' dry wood, from 4 to 5 years old . . .	3037
Ditto . . .	Highly dried in a stove	3450
Oak . . .	Common firewood, in chips	2550
Ditto . . .	In thin chips, well dried in the air	2925
Ash . . .	Joiners' dry wood	3075
Ditto . . .	Highly dried in a stove	3525
Maple-tree . .	Seasoned wood, highly dried over a chafing dish .	3600
Service-tree . .	Dried over a chafing dish	3600
Wild Cherry-tree .	Joiners' dry wood	3375
Ditto . . .	Dried over a chafing dish	3675
Fir . . .	Joiners' dry wood, ordinary	3037
Ditto . . .	In chips, well dried in the air	3375
Ditto . . .	Highly dried over a chafing dish	3750
Poplar . . .	Joiners' dry wood, common	3460
Ditto . . .	Highly dried in a stove	3712
Horn-beam . . .	Joiners' dry wood	3187
Oak . . .	Dry	3300

120. From the experiments on wood, previously dried, we shall have for a mean calorific power the number 3654; and for the ordinary oak firewood, 2550. The results obtained from all the other experiments on wood, designated as dry, but which had not been artificially dried, and which necessarily contained different proportions of water, must be received as uncertain. It is well to observe, that in taking 3654

[a] See Tredgold on Warming and Ventilating, p. 42, 3rd edition.

for dry wood, the corresponding number for wood containing 25 per cent. of water, will be 2740.

121. Hassenfratz made experiments on 28 species of wood, by means of the ice calorimeter; the extreme results which he obtained were, that a kilogramme of wood dissolved from 32 to 49 kilogrammes of ice*; and as a kilogramme of ice, in melting, absorbes 75 units of heat, the extreme limits of the heat evolved are, $32 \times 75 = 2400$; and $49 \times 75 = 3675$, which numbers nearly coincide with those obtained by Rumford for dry wood, and for that in an ordinary state of desiccation.

122. Marcus Bull has made a number of experiments, to determine the relative quantities of heat evolved from different species of wood, by means of the apparatus described (104). The mode of operating consisted, as we have said, in establishing an invariable difference between the temperature of the internal and external rooms, and which was maintained by burning a given quantity of combustible in the interior room. The activity of the combustion, which might be regulated at will, was so much the greater, in proportion as the heat developed by the combustible was less. In using equal quantities of different combustibles, it is evident that their calorific power would be in proportion to the time during which the invariable difference of temperature was maintained. This method, which only gives the relative value of the calorific power of the combustible, comprises too many sources of error, to allow us to receive with confidence the results obtained.

It will follow from the experiments of Marcus Bull, that exactly the same quantity of heat is not evolved by wood equally dry, as it has varied from 6 to 6.4. But these discrepancies should be attributed to the unavoidable errors in such complicated experiments.

123. We shall state two other experiments made on a large scale, which confirm the preceding results, one at the baths of Vigier "*du pont Marie*," the other at Vesserling. Though these experiments were not undertaken for the purpose of determining the calorific power of wood, nevertheless they may serve as a guide to it.

124. In the baths "*du pont Marie*," the heating apparatus is so arranged, that the smoke escapes at a temperature differing but little from that of the air. In an experiment carefully conducted nearly 200^k of barked wood (*pelard*) was burned in two hours; the effect produced was equal to the heating of 7180^k of water to 85°. Thus, $7180 \times 85 = 610306$ units of heat developed, which gives for each kilogramme about 3000, and $3000 \times \frac{5}{4} = 3750$ for wood perfectly dry, for that which had been employed did not contain more than 20 per cent. of water.

* See Tredgold on Warming and Ventilating, pp. 40, 41; 3rd edition.

125. The mean obtained at Vesserling, after several days' experiments on a steam-boiler heated with wood, was $3^k.24$ of steam for each kilogramme of wood; the smoke on entering the chimney was 250°, and it still retained 10 per cent. of oxygen; consequently, only half the oxygen of the air was employed in the combustion. From this it will follow, that the calorific power of wood is composed, 1st, of the quantity of heat contained in the steam generated, which is equal to $3.24 \times 650 = 2106$; 2dly, of the quantity of heat carried off by the smoke; then, as the weight of the air necessary for the consumption of 1^k of wood is 4.47 and 8.94, in supposing that half of the air has escaped combustion; and as the calorific capacity of air is the fourth of that of water, the quantity of heat carried off by the smoke has been $8.94 \times 250 \times \frac{1}{4} = 557$; 3dly, of the quantity of heat absorbed by the vaporization of the water contained in the wood, which is equal to $\frac{650}{4} = 162$. Thus, the calorific power of wood, deduced from this experiment, will be $2106 + 557 + 162 = 2825$; that of wood perfectly dry, will be $2825 + \frac{4}{3} = 3766$.

126. From what precedes, it will follow, that the quantity of heat evolved by 1^k of perfectly dry wood, is

According to Rumford	3654
According to Hassenfratz	3675
From the experiments at Vigier baths	3750
From the experiments at Vesserling	3766
Mean	3711

127. These numbers differ but little one from another, and nearly coincide with those obtained in supposing that the heat developed by the combustion of wood is merely derived from the carbon which it contains. In fact, common firewood, perfectly dry, contains about 0.52 of carbon; and for dry wood yielding 0.02 of ashes, the quantity of carbon will be only $0.52 \times 0.98 = 05.1$. But, from the experiments of M. Dulong, which we shall give hereafter, the calorific power of carbon is 7161; consequently that of wood will be $7161 \times 0.51 = 3652$. In taking for the calorific power of carbon the number 7800, as found by M. Despretz, the calorific power of dry wood will be $7800 \times 0.51 = 3978$.

128. The coincidence between the calorific power of wood, as deduced from direct experiments, and that resulting from the hypothesis, that the effect produced is uninfluenced by the oxygen or hydrogen, when they are in the necessary proportions to form water, will lead us to admit this general principle: *The quantity of heat developed by an organic combustible is equal to that produced by the combustion of the carbon which it contains, in addition to that derived from the excess of hydrogen.*

From this law a very important fact will follow: that in the decomposition of water there is as much heat absorbed as disengaged in its formation; moreover,

Digitized by Google

from this it will also result, that damp charcoal, which burns with flame, produces as much heat as the dry charcoal which it contains.

129. In recapitulating what has preceded, it will follow:

1st. That all wood in the same state of desiccation sensibly evolves the same quantity of heat.

2dly. That for all wood rendered perfectly dry by artificial means, the calorific power is 3600.

3dly. That for all wood in the ordinary state of dryness, containing from 20 to 25 per cent. of water, the calorific power varies from 2800 to 2700.

In estimating the calorific power of wood, strictly speaking, we should deduct the heat employed in the vaporization of the water which it contains, (*l'eau hygrométrique,*) and as being ineffectual, at least when the smoke escapes, which is generally the case, at a temperature above 100°; but as the number of units of heat employed to this effect are only from 130 to 160, and as these numbers are less than those representing the variations in the state of humidity, they may be disregarded.

130. We can furnish no accurate calculation as to the calorific power of wood in comparison to its volume, inasmuch as the weight of the same volume varies, not only with the density of the wood, but still more with the size of the fagots, their crookedness and manner of piling them.

The following results, obtained by M. Berthier, will show to what an extent they may deviate.

Nature of the Wood.	State of the Wood.	Weight of a cubic mètre in kilogrammes.
Oak of long standing from the neighbourhood of Moulins	Cut 1 year in split fagots	275k
Ditto	Cut in four parts	515
Oak of the forest of Monadier near Moulins	Large split wood, cut 3 years	386
Ditto	Cut in four parts	485
Oak from the neighbourhood of Cahors	Cut 1 year	525
Oak for making charcoal	Ditto, 30 inches long	220 to 262
Beech from the neighbourhood of Moulins	In large split billets	400
Ditto	Part worm-eaten	375
Birch from the neighbourhood of Moulins	In large billets	440
Aspen for making charcoal	. . . .	190 to 220
Fir from Moulins	In large wood	300 to 340

Digitized by Google

From this it will seem that, for each locality and for the species of wood employed, direct experiments are necessary to obtain with sufficient accuracy the weight of wood in a unit of measure.

131. The measure designated by the name of "*voie*" is 2 cubic mètres or 2 stères. The length of the fagots, according to law, is $1^{m}.14$, the measure of the stère is $0^{m}.88$ high by 1 mètre long. In Paris the weight of the "*voie*" of firewood varies from 700 to 750^{k}, that of charcoal-wood varies from 600 to 700^{k}.

132. *Effect produced by the different species of wood.*—Though all wood, when perfectly dry, is, for equal weights, susceptible of giving nearly similar quantities of heat, their structure causes a diversity in their mode of combustion, which prevents their indiscriminate application.

Compact wood only burns at the surface; the heat which has an internal effect disengages the inflammable gas, which is entirely consumed in the commencement, leaving but a voluminous compact mass of charcoal, which burns slowly and without flame. Light wood burns with much greater rapidity, as its porosity permits the air to enter more freely and separates it by the action of the heat; the greater part of the charcoal which it contains is consumed together with the combustible gas, leaving but little charcoal, and giving off flame nearly the whole time of its combustion. The difference between these two species of wood decreases in proportion as the fagots are smaller, the cause of which is evident.

From what has preceded, it may easily be imagined why it is that light soft wood is always employed in the porcelain furnaces, and also in the common pottery furnace, where a very high temperature is required with a long uninterrupted flame, whereas, for nearly all other purposes, where a less elevated temperature is requisite, and a more immediate contact of the fire, the hard woods are preferred.

Whatever species of wood may be employed, the calorific effect will be the greater in proportion as the wood is the more divided, as a smaller portion of air will escape the action of the combustible; in all cases the air must escape at a higher temperature than that of the atmosphere; and it may be easily conceived, that the less the quantity of air employed for the same quantity of material, the smaller will be the loss of heat by the air in escaping. But, independently of the expense of splitting the wood frequently, the nature of the operation prevents the using of small wood, as the combustion would be too rapid. There are but few manufactories, such as those of glass and porcelain, where a quick combustion is advantageous, as it always produces a higher temperature; it becomes in this case an object to employ split wood.

133. *Radiating power.*—The relative quantity of radiated heat disengaged by

Digitized by Google

wood in combustion is variable for the different woods, but when they are burned in very small pieces, the quantity is nearly uniform. We here give the result of an experiment on beech.

The temperature of the atmosphere was 20°; that of the water introduced into the vessel 17°.5; by the combustion of $97^{g}.5$ of wood, it was raised to 22°.5; thus the quantity of heat absorbed by the water elevated its mass 5°; the quantity of water contained in the apparatus was $11^{k}.29$; the weight of the vessel was $2^{k}.223$; as the calorific capacity of tin is 0.11, the quantity of heat absorbed by the vessel is equal to $2^{k}.223 \times 0.11 = 0^{k}.244$ of water, raised 5°; consequently, the quantity of heat absorbed by the apparatus $= (11^{k}.291 + 0^{k}.244)\ 5° = 57.65$ units of heat.

Now, from what we have said, (108,) the total quantity radiated $= 57.65 \times 1.36 = 78.40$ units. But, according to paragraph 129, 1000 grammes of wood should give in burning 2800 units of heat, which is consumed by the current of air and by radiation; consequently, $97^{g}.5$ should produce 273. Thus the quantity of heat dispersed by radiation, is to the total quantity developed :: 78.40 : 273 :: 1 : 3.48, or approximately :: 1 : 3.5; consequently, the quantity of radiated heat is to that carried off by the current of air :: 1 : 3.5 − 1 :: 1 : 2.5.

This ratio is much more considerable than has been heretofore supposed; but it is still greater when the wood is burned in a large mass, so as to produce a considerable volume of charcoal, as the radiating power of charcoal, which we shall hereafter see, is much greater than that of flame.

ERRATA.

Title Page, *for* "of the Society of Encouragement," &c., *read* "of the Council of the Societé d'Encouragement," &c.

Page 7, paragraph 9, last line, *for* "fixed together," *read* "superposed."

Page 11, paragraph 19, line 4, *for* "is proportioned to the line of the angle," &c., *read* "is as the sine of the angle," &c.

Page 12, paragraph 24, line 4, *for* "the most difficult," *read* "is the most difficult."

Page 20, title to table, after 100° put a comma, and *for* "on one square centimètre," *read* "on a square centimètre."

Digitized by Google

HARBOURS.

THE all-important subject of an improved means of speedy internal communication has now become of national necessity; a harbour of refuge and packet station for communication with Dublin, therefore, claims immediate attention; and as various reports have been made in relation thereto, we give in this Part, in addition to Mr. Page's Report, a comparative statement of the area of each harbour, with the length of breakwater and pier, considering that, as the estimates differ, it is better to compare the lengths of the breakwaters than the amount of the estimates.

	Mr. Walker's. Acres.	Capt. Beechey's. Acres.	Mr. Rendel's. Acres.	Mr. Page's. Acres.
The area in and at low-water of spring tides	90	176	316	1525
Area two fathoms deep and upwards	80	131	252	898
Area three fathoms deep and upwards	70	110	216	641
Area four fathoms deep and upwards	40	69	188	480
Area five fathoms deep and upwards	17	43	127	304

By reference to this table it will be seen that for every 1,000 yards of breakwater,

Mr. Walker	incloses	47	acres.
Capt. Beechey	,,	72½	,,
Mr. Rendel	,,	126½	,,
Mr. Page	,,	457	,,

Mr. Page's Report will be read with lively interest; it is singularly confirmatory, in estimate, to the one made by Sir John Rennie, published in our previous Part. We have found Sir John's Report much appreciated by those who have professionally and otherwise considered the subject. We are induced, therefore, to add the present Report as another equally scientific and practical.

Digitized by Google

REPORT OF THOMAS PAGE, CIVIL ENGINEER,

ON THE ELIGIBILITY OF HOLYHEAD AND PORTH-DYN-LLAEN, AS HARBOURS OF REFUGE AND PACKET STATIONS FOR COMMUNICATING WITH KINGSTOWN.

2, Whitehall Yard, 30 April, 1844.

MY LORDS AND GENTLEMEN,

In accordance with your instructions "that I should proceed at my earliest convenience to examine the localities of Holyhead and Porth-dyn-llaen, and report to you my opinion upon them, as to the comparative eligibility of each as a packet station for large steam vessels, serving as a point of departure from the coast of Wales to Kingstown, with such observations upon the winds and tides as might influence the passage, and also as a harbour of refuge for the channel trade; and lastly, upon the effect of any bridge over the Menai on the navigation of the straits, and the expediency of railway transit upon the bridge," I beg leave to state that I proceeded to Holyhead and thence to Porth-dyn-llaen, and after an examination of the two places, and reference to the Charts and Admiralty Survey of that coast, together with the opinions of several nautical officers on points wherein information exclusively belonging to them was desirable, I have now the honour of submitting to you the following observations:—

The importance of the subject, whether with relation to the means for diminishing the great sacrifice of life and property which is annually suffered by shipwreck, or to the best mode of effecting the most certain and rapid communication between this country and Ireland, (a communication of increasing interest both political and commercial,) and the difference of opinion which has been expressed by the naval officers and engineers previously consulted, impressed me with the conviction that all the attention which I might be permitted to devote to it, would be requisite, in the attempt to treat it as it deserves, and that much caution would be called for in discriminating between the statements already put forth, and others which might be made to me in the

Digitized by Google

course of my inquiries. This caution has not been lost sight of in deducing the conclusions to which I have arrived.

Although your instructions refer, 1st, to the port as a packet station; 2ndly, to the harbour of refuge; and 3rdly, to the bridge and navigation of the Menai, I shall consider them in the order in which they are best disposable.

OF THE HARBOUR OF REFUGE.

A harbour of refuge should, in my opinion, be chosen with regard to the following objects:

That it should afford shelter and security for vessels which otherwise must be driven on a lee-shore.

That, with depth of water for large ships, the holding-ground should be sufficiently good to bring a ship up, which may enter it in a gale of wind.

That the nature of the shore should be such as to allow of vessels saving themselves, or at least the crews and cargo, by beaching upon it; and where the formation of a breakwater may be required, it should be so disposed that no injurious effects should result in decreasing the depth of water, &c.

That it should possess an easy access for a disabled ship during the most violent gales, and that its position, if determined solely with regard to saving life and property, should be such as to afford a refuge on that coast, where, from the direction of the winds and tides, wrecks are most prevalent.

If to these requirements it affords room for working out of the harbour during contrary winds, it will comprehend almost all the requisites for a perfect harbour of refuge.

It is evident that most of these conditions can only be fulfilled in a locality where nature has done much, and where art has to do little; and this conclusion involves another material consideration in the inquiry, namely, the expense, which under the conditions proposed would be the least possible.

The features of the two localities of Holyhead and Porth-dyn-llaen, with regard to their natural advantages for a harbour of refuge, are strikingly different; but a description of them will be best given from the "Sailing Directions for North Wales," 1st July, 1843, published by order of the Lords Commissioners of the Admiralty, inasmuch as they particularize those points most essential in the consideration of this part of the inquiry.

Digitized by Google

OF HOLYHEAD.

"The edge of the coast from Ynys Wellt is low and rocky as far as Holyhead Harbour. Off Ynys Wellt there are a number of detached rocks, but as they are close into the point, and scarcely ever cover, they cannot be called dangerous; and the coast, therefore, may be safely approached till near the Outer Platters, which are a patch of foul ground, lying about one-third of a mile N.N.W. of Ynys Gybi; they do not uncover, and at low-water spring tides carrying as little as two feet water, they become dangerous to vessels running for Holyhead Harbour. There is a channel inside the Outer Platters, but as foul ground extends for some distance from both Ynys Gybi and Ynys Wellt, it would be imprudent to use it without the assistance of a pilot.

"From the north-east end of Ynys Gybi, the foul ground extends off shore about two cables' lengths, with only seven feet at low-water springs. The Inner Platters are another small patch of rocks, lying near the pier, and just a wash at low-water, but so close in, and out of the reach of vessels, that they need no especial description."

"Holyhead Harbour is a narrow inlet about half a mile in length, but it partly dries at low-water, leaving a surface of mud, upon which such vessels as take refuge can be aground, or they can moor to the pier. The ground outside of Holyhead Harbour, along the south-eastern shore, is all foul, and the low-water rocks uncover to a considerable distance."

Besides these extracts from the description in the Admiralty Survey, may be mentioned the Stag Rock, the Nimrod Rocks, the Pibeo Rocks, and others referred to in Captain Beechey's Survey as follows, wherein he states, "I have found some other dangerous rocks in this bay on the east side, and indeed one near this harbour, between the Stag and the Nimrod; there may be others."

"With the wind from W.N.W., round by the southward to E.N.E., shelter will be found in Holyhead Road; but with all other winds it is exposed to a heavy sea in blowing weather."

"The Race may be said to extend about a mile and a half off shore, and its chief strength is between the two Stacks. The worst sea there, is with the wind from N. to N.W., and even with S.W. and south winds, when blowing hard at the height of the springs, it is dangerous for small vessels; but with the wind from the eastward, smooth water may generally be expected. The worst part lies about N. by W. from the South Stack light, and distant from it exactly half a mile, and will be avoided by

Digitized by Google

not bringing the Skerries light to the northward of N.E.E. ½ E. In bad weather it will be prudent to keep, if possible, outside of the Race."

The whole coast being rock, with rocks protruding under low-water, the anchorage available must be the result of drift, and not a natural formation; and this opinion is borne out by the statement in the Survey, that the anchorage being goodi n any part of the bay, by keeping about a mile from the land, is confined to "moderate winds." Along the whole coast there is no place where a vessel can beach in a heavy sea with a chance of safety; and the consequence of a failure in making the harbour may be gathered from the statement given by Mr. Evans, the harbour-master, in which he says, "that several vessels going into Holyhead Harbour have been lost on the rocks to leeward, in consequence of not having proper sails set and anchors ready to drop." This description of the coast and holding-ground, confirmed by several statements which have been made to me, and the observation from the Report of the Select Committee on Shipwrecks in 1836, page 7, that 39 vessels[a] were on shore in Holyhead Bay, 20 of which were totally lost, with all their crews on board, are sufficient to prove that, for the purpose of a harbour of refuge, the natural advantages of Holyhead, as they relate to its coast and holding-ground, are very limited. Its bold headland is, however, easily made; it has an efficient establishment for assisting vessels in distress, and by whose activity, under the able directions of Mr. Evans, the harbour-master, a great number of vessels has been saved, which, from the nature of the coast, must have been totally lost. A chain has been moored across the entrance to prevent vessels dragging out, and indeed nothing seems to have been omitted to overcome those disadvantages which, as a harbour of refuge alone, nature has assigned to it.

OF PORTH-DYN-LLAEN.

The bay of Porth-dyn-llaen seems to have been well known to the Admiralty surveyors in the time of Lewis Morris[b], who speaks of it and of Nefyn as follows: "These are very safe and excellent harbours for ships that may be driven by stress of weather into Caernarvon Bay. The pier at Porth-dyn-llaen, which was begun to

[a] The statement in the Report of the Committee is, "That no less than 39 vessels were seen on shore in Holyhead Bay at one time, 20 of which were totally lost."

Referring to the evidence of Captain Evans, p. 77, it will be seen that this number is, however, the result of several years' observations.

[b] For reference to the chart, and observations by Lewis Morris, I am indebted to Capt. Beaufort, R.N., Hydrographer to the Admiralty.

Digitized by Google

be raised by a gift of £600 from King George the First, but never finished, is now almost in ruins, and if not looked after, this excellent harbour will be greatly destroyed.

"There is a small pier at Nefyn, which is found very useful for the herring-fishery and coasting vessels. This pier is falling to decay."

In the Admiralty "Sailing Directions for North Wales" (1843), before quoted, the bay of Porth-dyn-llaen is described as "clean throughout, with the exception of the rock called Carreg-y-Chwislen, which may be approached within 50 yards on all sides, is two cables in length from Porth-dyn-llaen Point, leaving a clear sound with five fathoms. The bottom is sand over clay, and the depth decreases gradually to the beach. In its present state the bay affords no shelter with the wind from W.N.W. to north [a], but from all other points of the compass it may be adopted as a convenient and safe anchorage."

In the bay of Porth-dyn-llaen, as also in the adjoining bay of Nefyn, there is an extent of coast of 5,000 yards in length, in which a vessel may beach; the holding-ground is sand over clay, the latter appearing in many parts through the sand, between high and low-water marks. Protected by its own promontory, and the high lands behind it, from the prevailing gales, and shut in by the Rivels from the east, it is open to few points of the compass.

The Rivel mountains, whose peculiar summits distinguish them from any others on the coast, the cliff called Carreg Llam, and the mountains of Carn Bodfearn and Carn Madryn, afford excellent landmarks, the advantages of which may be better described from the Admiralty "Sailing Directions."

"The general character of the coast, up to the point at which it turns towards the Bar of Caernarvon, is high, but gradually lowering to the water's edge, being in fact the foot of a lofty and steep range of mountains; the most remarkable of which is the Rivel, or, as it is called by the Welch, Yr-Eifi, and one of the best landmarks in Caernarvon and Cardigan Bays. From the northward, in rounding Holyhead, it shows three remarkably sharp peaks: the middle and highest of these is 1,866 feet above the sea, to which it rapidly slopes down, and terminates in a noble and picturesque cliff, forming with the peaks, so remarkable a feature in the coast that it is impossible to mistake it, and therefore serving as an infallible mark for knowing the land, and determining a vessel's position. Between it and Porth-dyn-llaen, the stupendous cliff of Carreg Llam rises almost perpendicularly from the water to the height of 400 feet, with clouds of sea-fowl always hovering about it; and this cliff at once leads the eye to Porth-dyn-llaen Bay.

[a] Seven points.

Digitized by Google

"The general set of the tide in the bay is from the eastward along the shore, and through the sound for nine out of the twelve hours. In the former case it is very gentle, even at the springs; but in the sound, it then runs three knots."

Comparing, from this accurate description of the two localities and my own observations and inquiries, their natural capabilities in the most important features which may fit them for harbours of refuge, viz. *the holding ground*, which in one is a natural formation, clay to the surface, and which has enabled vessels to ride out tremendous gales, and in the other the probable result of drift—*the facility of beaching* so extensive at Porth-dyn-llaen, and so limited, if any can be assigned to it, at Holyhead, *the shelter afforded* to vessels by the natural protection in each place—*and the strength and set of tides* which are regular and gentle at Porth-dyn-llaen, and amount to a race in the neighbourhood of Holyhead—I am decidedly of opinion, that for a harbour of refuge the bay of Porth-dyn-llaen is preferable to the bay of Holyhead.

In coming to this conclusion, I have considered all the objections which have been made to the bay, and am of opinion that some of the circumstances stated as objections afforded arguments in its favour; such, for instance, as the long ebb tide of nine hours, causing an indraught into Caernarvon Bay, which tide being an off-shore tide at Porth-dyn-llaen, is opposed to the prevailing winds, and would assist a vessel coming in at the east entrance. The tide also, both ebb and flood, running through the sound would maintain such depth of water in-shore as it might, for other purposes, than those of a refuge harbour, be desirable to maintain.

Another advantage which Porth-dyn-llaen possesses, is the shelter afforded in all gales from the eastward on the west side of the point, where the Holyhead sailing packets have occasionally landed their mails and passengers when they could not get into Holyhead.

With regard to the high ground enclosing the bays of Porth-dyn-llaen and Nefyn, which consists of sand over clay, but with slight exceptions grassed over, I have satisfied myself, by careful examination, that any slip in this part is attributable to the land springs, and that there is every facility and abundant space for the construction of buildings and docks which may be required, with very little labour or outlay; the stone being at hand, the space at low water being 750 feet, and the bottom being clay, will confirm this opinion.

The stress which has been laid upon the advantages attributed to Holyhead in being well lighted, I have not overlooked; but it is evident that of the lighthouses enumerated, all of them, excepting the pier light, would be requisite for the navigation of that part of the Channel, if there were no harbour at Holyhead, and even were they

Digitized by Google

not requisite, surely in the consideration of a subject of such moment, we should not reason on bringing the harbour to the lighthouses, but the lighthouses to the harbour.

A light on the point of Porth-dyn-llaen (which projects 3,500 feet from the shore) would be of essential service in the navigation along this coast, as it would form the connecting link between the light on Bardsey Island and the South Stack, and, with a subordinate light, would give a vessel making Porth-dyn-llaen the advantages now attached to Holyhead.

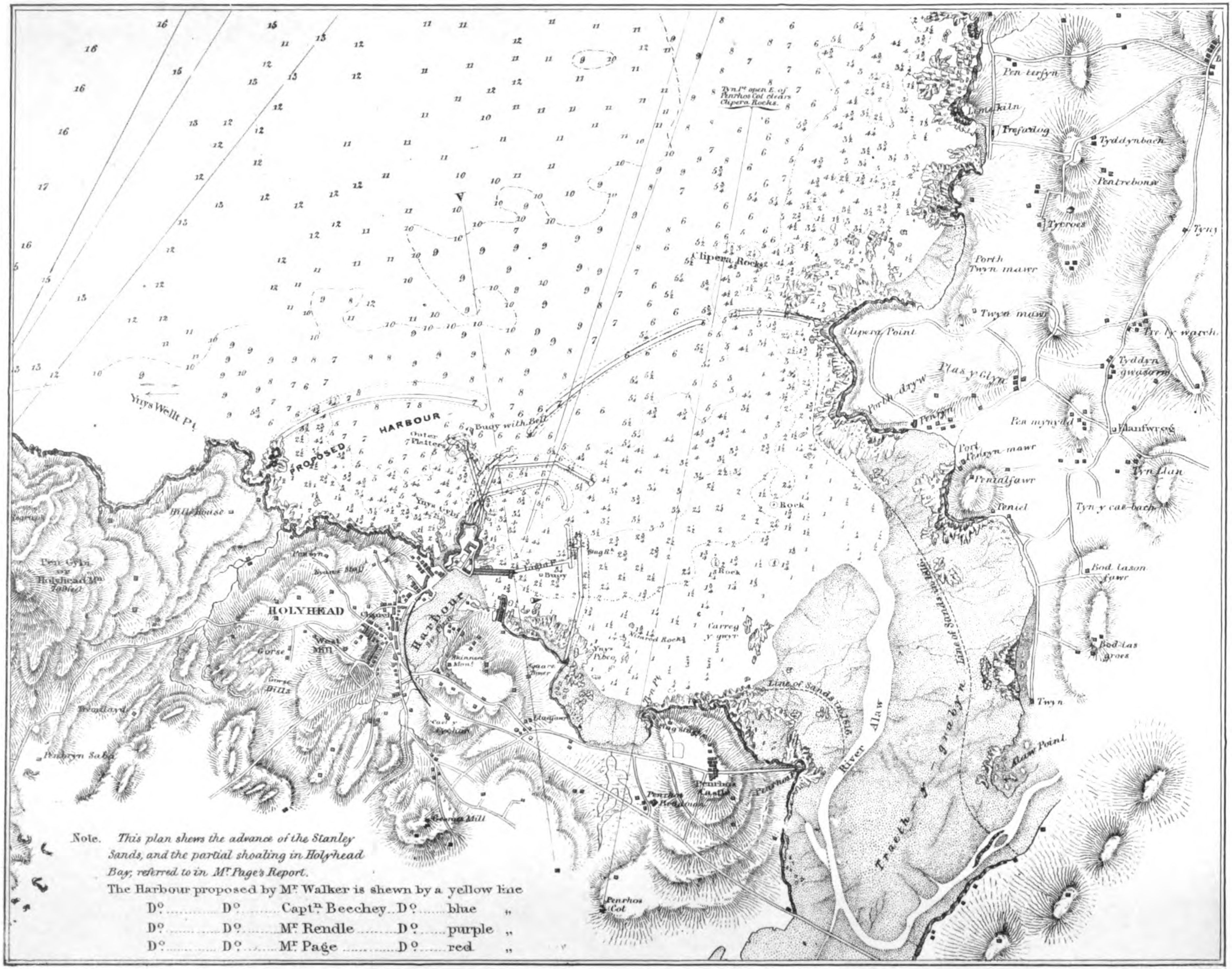
On the subject of the drift apprehended from the Menai, (which has been alluded to in one of the Reports on this subject, though the Menai is fourteen miles distant on the coast,) I am of opinion that there is no reason for any such apprehension. Beyond Rivel Head is a low shingle beach with large loose stones; and other "shingle beaches, with stones in patches, between Trwnytal Point and Belan Point," are mentioned in the Admiralty Survey, which do not indicate any drift of sand. Moreover, a drift into the bay of Porth-dyn-llaen would accumulate on the clay, which, as I have remarked, actually projects through the sand in several places between high and low-water marks; and the fact of the African steamer, when she anchored in the bay, having brought up clay on the fluke of her anchor, (a parallel case with many others,) shows no accumulation of sand below the low-water line. It is, however, right to refer to a sounding marked as six fathoms on Lewis Morris's Chart, where, in Commander Sheringham's Survey, not more than thirty feet are shown. As this is in the sound, where the depth of water would be maintained by the tide, the difference is not easily accounted for.

On visiting both Holyhead and Porth-dyn-llaen, the results of inquiries were as contradictory as those which have appeared in other Reports upon the subject; and there was such an evident partiality in the answers to one or other of the ports, that I have not considered it safe to rely implicitly upon either, but have come to the conclusion with respect to a refuge harbour from disinterested information, which, it is satisfactory to me, coincides with the views stated in the Admiralty Survey.

Referring to the position of Holyhead and Porth-dyn-llaen as refuge harbours for the Channel trade, it is evident that the value of either, in this point of view, depends on the position of the ship and the direction of the gale. The object with outward-bound ships is to maintain their distance, and to effect this they would run to the nearest port, supposing the advantages of both equal; but for vessels which otherwise must run ashore in Caernarvon Bay from Bardsey Island to Holyhead, (and even in Cardigan Bay, provided they can clear Bardsey Island,) Porth-dyn-llaen would afford, at an inconsiderable outlay, a ready and safe harbour; and the necessity for

Digitized by Google

Digitized by Google



PLAN OF HOLYHEAD BAY TAKEN FROM THE SURVEY BY CAPT. BEECHEY IN 1840, SHEWING THE VARIOUS HARBOURS WHICH HAVE BEEN PROPOSED THERE.

such a harbour may be shown by the fact that there are ten vessels wrecked on this coast of Wales for one that is wrecked on the opposite coast of Ireland. Although situated in Caernarvon Bay, the port is not in a position to be called "deeply embayed," being not more than three nautical miles further than Holyhead Harbour is, to the eastward of a line drawn from Bardsey Island to the South Stack; allowing that rock a berth of two miles, as recommended in the "Sailing Directions" for the coast. An outward-bound vessel leaving Porth-dyn-llaen would therefore be in the Channel as soon as one leaving Holyhead.

Vessels passing down the Channel from the Clyde and the ports of Cumberland generally keep on the Irish coast, making Wicklow Head, which is immediately opposite Porth-dyn-llaen: to all these vessels, therefore, and to others coming from the southward, which could not pass Holyhead, it would be highly advantageous as a refuge harbour; whereas, with regard to Holyhead, any vessel that could round that promontory would find refuge in Bull Bay, Red Wharf Bay, or in Ramsey Bay in the Isle of Man, according to their destination.

Respecting Holyhead Harbour as it is at present, I may observe that at low water it contains only 4½ acres varying in depth from 11 to 6 feet, and 6 acres varying in depth from 6 feet to 0, and that at the pier, (which was constructed especially for the Post-office packets, and not with a view of forming an asylum harbour,) the then depth of water was 14 feet at low-water spring tides. Comparing the soundings at that time with those in the Survey of Captain Beechey in 1840, I find a decrease in the depth of water of from three to four feet; and with reference to my own soundings, there is not more than nine feet six inches average depth of water at low-water springs.

This circumstance, coupled with the expense annually incurred for dredging, shows that a deposit is continually taking place, and that without recourse to means for removing it, sufficient depth of water could not be maintained for the packets.

This conclusion will not be affected in the least by the note appended to the Report of Admiral Sir James Gordon and Captain Beechey, in which it is mentioned that "some implements lost in 1817, outside the pier-head, were found by the workmen employed in the diving-bell in 1831;" and which is adduced by those officers as a proof that a harbour at Holyhead would not be likely to fill up. A sea which occasionally breaks with great force over the pier may be supposed to keep the bottom outside the pier-head free from deposit; but the observations on deposit apply to the bottom when inclosed as a harbour.

As the silting up has gradually taken place inside the pier, any extension of the pier (other circumstances affecting it being unchanged) would be followed by the same

Digitized by Google

result, viz. an extension of the deposit; besides, it is evident that an extension of the pier would not include sufficient space for the number of steam vessels which might be calculated on, if Holyhead be selected as the point of communication with Kingstown.

In the plan proposed by Mr. Walker for a harbour at Holyhead, (Report, 6 October 1843,) and on which you request me to state my opinion, it will be seen that not only is it intended to extend the present pier, but to inclose part of the bay by a breakwater from the northern point of Ynys Gybi, leaving an entrance of 300 to 350 feet in width on the eastern side.

The objections to this plan which I may be allowed to suggest are, that a ship which can enter it must come in in the very teeth of the prevailing gales, an objection which applies to the present harbour, and from which cause, as stated in the "orders" of the harbour-master, many vessels have been lost on the rocks; also that the width is not sufficient to insure the entrance of disabled ships, even were it more favourably situated; the opinion of nautical authorities (who in fact are on this point the only authorities to be relied on) being that 700 to 1,000 feet would not be more than sufficient; and another objection to it is, that by encroaching so much upon the bay, it subjects a ship which may miss the entrance to greater danger by driving her so much nearer to a lee shore.

It will be seen that in some of the requisites cited by me for a harbour of refuge, namely, good holding ground, and a shore on which a ship may beach, (in case of damages which would sink her in deep water,) I differ from Mr. Walker, who considers that "the bad holding ground outside the harbour will be of very little consequence, if vessels by entering the harbour have little or no occasion to anchor outside; and the same reason renders the rocks round the bay comparatively harmless." These remarks apply altogether to vessels inside, but there are numerous cases, as I have before pointed out, where vessels have missed the present entrance, which is more than 120 feet wider than that proposed, and in a less exposed position, and have been lost in consequence on the rocks.

Admitting it is of less moment that the holding ground should be good inside a harbour whose entrance is opposed to the prevailing gales, yet its importance in this position on a rocky coast, may be attested by the six wrecks in Kingstown harbour, during the late gales.

The entrance to a refuge harbour should be made, not so much for a ship fully

[a] Captain Bullock's Evidence before the Select Committee of the House of Commons on Shipwrecks, 10th August, 1843, p. 285.

Digitized by Google

rigged and well manned, like a ship of war, but with regard to the condition of a merchant vessel, with a thin crew harassed by fatigue, disabled in her rigging, and altogether ill-calculated to steer very nicely into a pier harbour [a].

There is, moreover, another consideration, which seems to have escaped altogether the notice of those who have examined and reported upon the harbour of Holyhead, namely, *the progressive advance of the Stanley Sands;* to show which more clearly, I append to this Report a Chart, on which the sands and soundings in the bay, from Mr. Thomas's Survey in 1816, are compared with the same in the Survey of Captain Beechey in 1840, and by which it will be seen that the sand has advanced $5\frac{1}{2}$ cables (more than half a nautical mile) in 24 years, in a place where the depth of water at low water varied generally from three to eight feet.

That it is still nearly a mile from the entrance of the proposed harbour, and that the rate of increase, as it enters deeper water, will be comparatively much less, are true; but as the proposed harbour would be free from any run of tide, and this drift is gradually approaching it, the effects of accumulation at some future time (probably at no great distance) should now be taken into serious consideration, and should, together with the naturė of the holding ground, be treated by more geological knowledge than has yet been brought to bear upon it. What proportion of these sands is due to the detritus of the river Alaw, and what due to the drift from the sea, are questions which ought, certainly, to be determined before any plan involving the expenditure which must be required for a harbour in the bay, can be acted upon.

This inquiry is of the greatest importance, inasmuch as by comparing the surveys of Mr. Thomas and Captain Beechey, a diminution of a fathom in the depth of soundings is shown in 1840 on the site of the proposed harbour.

A reference to the expense incurred at Howth Harbour, (an amount exceeding £400,000,) which, by the want of attention to the precautions here suggested, was altogether thrown away, will show the importance of this consideration [b].

[a] So much is a pier harbour generally dreaded, that in cases with which I am acquainted, a pilot who has been requested by the owner of a ship to run for Ramsgate harbour, has given his opinion that he would sooner beach the vessel at Sandgate than run the risk of clearing the pier-head; yet, to this harbour, all ships pay a passing toll, the amount of which increases with the size of the ship, so that the ship contributing the greatest amount can never enter the harbour to which she pays.

[b] The position of Howth Harbour, with relation to course and distance, is preferable to that of Kingstown for the run to Holyhead, and the change affords an instance of the shortest distance not having been a primary consideration in the selection of a port. It is worthy of remark that the Kish Bank was brought up as an objection to the passage between Holyhead and Kingstown, in the same manner that it has been in the discussion about Porth-dyn-llaen.

Digitized by Google

SUGGESTIONS FOR PORTH-DYN-LLAEN AND HOLYHEAD.

The arrangement I would suggest for a refuge harbour at Porth-dyn-llaen, which by the form of the bay will allow of a harbour of great or small capacity, is shown on Plan No. 1; it contemplates the extension of a breakwater from Carreg-y-chwislan to the eastward, which can be terminated at any point consistent with the area of sheltered anchorage required. With 5,600 feet of breakwater, it would protect 400 acres, varying in depth from 12 to 30 feet; or by an extension in another direction, of 8,650 feet, the space inclosed would amount to 960 acres. The Sound is proposed to be kept open, allowing easy access for vessels in that direction, and continuing the outlet for the sweep of the ebb tide round the bay, without interruption. Thus, the existing state of the shore and of tide would not be much interfered with, an object of importance with regard to its future maintenance.

Few localities are so well provided with the materials for the construction of works as Porth-dyn-llaen. The greenstone of the point, which will afford large blocks, (samples of which may be seen on the old quay,) the granite of Penrhyn-Bodfilias, and of the Mount Gwyliwr—all of which I have carefully examined, and which may be obtained at a low cost—leave nothing to be desired for a stone structure; and, as I have before observed, there is every facility for the construction of packet berths and other works required on the shore.

At Holyhead, the most judicious course, in my opinion, would be to inclose the bay between Ynys Gybi and the Clipera rocks by a strong breakwater, leaving two entrances of 800 feet in width; the length of the breakwater would be 9,900 feet (4,600 feet longer than that proposed by Mr. Walker); but the area inclosed, limited by soundings of 12 to 38 feet at low water, would be 900 acres, being 820 acres more than the number contained in the harbour referred to, namely, 80 acres.

The value of this proposition, or indeed of any other, would depend on the result of that geological investigation of the sands to which I have alluded.

Another arrangement for a harbour by a breakwater from the rocks eastward of Ynys Wellt Point to the Outer Platters, (shown on the Plan No. 2,) which, with about the same length of wall, would inclose nearly double the area of Mr. Walker's proposed harbour in this position; the holding ground would, I fear, be an objection, but the site would be free from drift. I am informed, however, by an intelligent officer in the packet service, Commander Davis, that if a harbour is to be formed at Holyhead, it should be still further westward, to prevent the liability of ships being wind-bound, as they now are, in the bay.

Digitized by Google

OF THE ESTIMATES[a].

On the subject of the estimates for a harbour at Porth-dyn-llaen, or at Holyhead, it must be remarked, that in the former case all the material is on the spot, and in the latter, a great portion must be obtained from the Penmon quarry or other quarries in Anglesea, at a considerable distance, supposing the limestone to be used. Taking the filling as Holyhead stone, and with prices obtained of contractors for the other, the following are the estimates for the harbours according to the sections of the breakwaters contained on the Plans Nos. 1 and 2.

PORTH-DYN-LLAEN.

		£
Breakwater, as suggested on Plan No. 1, to inclose	960 acres.	1,021,000
Ditto . . . . . . ditto . .	400 acres.	411,000
Ditto . . . . . . ditto . .	100 acres.	200,000

HOLYHEAD.

Breakwater, as suggested on Plan No. 2, to inclose 900 acres.	1,872,000
Breakwater and extension of pier, as proposed by Mr. Walker, to inclose 80 acres	915,000

OF THE PORTS OF HOLYHEAD AND PORTH-DYN-LLAEN AS PACKET STATIONS.

The advantages of either port as a packet station depends upon other considerations than those taken into account for a refuge harbour.

The precision with which a steamer can be managed, compared with a sailing vessel, renders the access to the harbour generally of less importance; and the rocky shore of Holyhead, or beach of Porth-dyn-llaen, will therefore not be considered for or against, on this part of the subject. There are, however, points of great importance on which opinions differ, and which nothing but trials can fairly set at rest: these are the facility with which each port can be made, and the comparative length of the voyages.

On the facility with which each port can be made, opinions are given in the Appendix to the Report of Admiral Sir James Gordon and Captain Beechey, and also in that of Mr. Walker; but of the five officers whose letters are appended to the

[a] Although the estimates are not given in detail in this Report, all the quantities have been carefully calculated at fair prices.

former Report, four had not visited Porth-dyn-llaen, and the fifth is uncertain; and of those in the Appendix to the latter, four had not been there, two do not state if they had or not, and of the remaining two, one is in favour of Holyhead, and one for Porth-dyn-llaen.

The conflicting statements found in these letters, as to depth of water, &c., which a single glance at the Admiralty Charts would correct, and the similarly conflicting assertions which have been made to me both at Holyhead and Porth-dyn-llaen, induce me to rely most on the impartial statement of Commander Sheringham, who is intimately acquainted with the whole coast, and whose descriptions of the facility of making both are given in the Admiralty directions, and by which and even the statements referred to, there appears to be no advantage in either case.

Regarding the comparative length of the voyages, which, on a superficial view of the subject, would be estimated by the distance, a remark in the Report of the Irish Railway Commissioners[a], though applied to land communication, is of such moment that I shall here quote it. "In making comparisons of this kind, the actual distance is commonly assumed as the measure of the time, a form of calculation sufficiently accurate for ordinary purposes, and where other circumstances concur in favour of a particular conclusion; but in a nicely balanced case, time being the only or principal consideration, it should be well understood that a mere comparison of distances may often prove a fallacious mode of estimating the time necessary for travelling over a given space. There may exist on the one hand peculiar and unavoidable causes of delay, such, for example, as will be presented in the passage of the Menai Strait on the Holyhead line, while inferior gradients, should they prove so, may retard the progress equally on the line to Porth-dyn-llaen.

To this may be added, that, in the present case, as the object is not the attainment of the shortest passage under favourable circumstances, but *a series of passages which shall include the greatest average of rapidity and regularity*, so the effects of wind and tide may be more than sufficient to counterbalance the difference of distance.

To enable me to express an opinion on this part of the subject, on which so little in reality is known, I have procured copies of the Register of Winds at Holyhead[b] during the last three years, and have had them arranged with the force due to each, on the points of the compass, showing the number of days on which each wind pre-

[a] See Report of the Irish Railway Commissioners, July 1838, p. 72.

[b] To the Table of Winds at Holyhead is added a Table from the register kept at the Royal Observatory at Greenwich, with the mean force. This Table was compiled before the register at Holyhead was obtained. A great difference in the force will be observed.

Digitized by Google

vailed, and the mean force; the product of which may be used for expressing the effect of each wind upon the voyage. In the period referred to, it will be seen that the result corroborates the generally received opinion that the prevailing winds are considerably more in favour of the passage between Porth-dyn-llaen and Kingstown than between Holyhead and that port; that the beam winds[a] are more than 50 per cent. in favour of this passage, and those against the ebb tide in a much higher ratio. The results being given in the tables accompanying this Report, it is not necessary for me to go into further particulars.

The advantages which Porth-dyn-llaen possesses over Holyhead in position, as regards the prevailing winds, has been mentioned by Captain Beaufort, the Hydrographer to the Admiralty, in his Report, dated 4th November, 1836, in which he states, "that the courses would be W.N.W. and E.S.E., so that the most prevalent wind (S.W.) would be a side wind both ways, an advantageous circumstance to steamers, as it enables them to steady themselves by canvass."

It has also been referred to in the letter of Lieut. Philipps[b], who thinks "that Porth-dyn-llaen would be exempt from the strong tides and heavy sea of the race of Holyhead, and that the difference in crossing the Irish banks would be very trifling."

I may here also refer to the opinions of Commander Davis and of Lieutenant Hosken, the commander of the Great Western steam ship, to whom, as well as to others, I particularly referred on this subject, to ascertain the value of the $2\frac{1}{2}$ points, which is the difference between the courses from Porth-dyn-llaen and Holyhead. The former states, "that a favourable wind will give two to three knots, according to the roughness or smoothness of the sea;" and the latter, "that the advantage would be very considerable on the part of the vessel having the wind on the beam; that the difference in fast vessels would be two or three knots." These remarks were not made with any reference to the advantage of one port over the other.

[a] The following paragraph from the *Nautical Magazine*, April 1844, bearing on this subject, may be interesting:—"The cause we should assign for a 'beam wind' being the best to produce velocity in a ship is, that the position of the sails with reference to the power of the wind, allows every inch of canvass to become exposed to the pressure; and therefore the propulsion must, abstractedly considered, be in excess over that which is given on any other point of sailing; all the angular sails act, and there is less 'bellying' of the square sails; and according to the stability or stiffness of the vessel, so will the advantage be regulated. It is obvious, too, that the full pressure of the wind is exerted upon the whole of the sails, which is not the case on a wind, for then the direction of force is oblique, and the lee portion of the sails becomes almost useless; and with the wind right aft, though a greater number of square yards of canvass should be spread, the sails on the masts being in a line ahead, a portion of the effective force is lost or but partially supplied."

[b] Appendix to Mr. Walker's Report.

Digitized by Google

With regard to the tides, Holyhead being the promontory round which the stream of flood sets with great rapidity as it fills the Bay of Liverpool and the great expanse between the coast of Ireland and that of Cumberland, a steamer must stem this tide for a considerable distance, and again, on the ebb, must be subject to the stream as the waters northward empty themselves through the channel into Caernarvon Bay. Both these effects must retard the passage, and require great allowance for correction of the course, which I am informed amounts sometimes to two and even to three points.

A steamer from Porth-dyn-llaen would have the flood in her favour towards Kingstown, and the ebb with her from that port; the ebb would be against her from Porth-dyn-llaen, but the beam winds would be in her favour: thus the position of the port, and the effect of the winds and tides, would be towards a regularity of passage, which it would appear is not attained by the Holyhead line, the length of some of the passages to Holyhead *causing a delay*[a] *of two hours in the general transmission of the mails* to London. These long passages have generally occurred with the wind at E.S.E., and the long passages in the contrary direction with the wind at W.N.W. The very circumstance affords sufficient proof that the diminution of distance between two points affords very little facility for rapid and regular communication, if the effects of wind and tide are adverse; a remark which will be illustrated by the subjoined table, showing the long passages between Holyhead and Kingstown in each direction during twelve months, in 1841 and 1842.

[a] See Report of Irish Railway Commissioners, July 1836.

Digitized by Google

DATE.		Name of Packet.	LENGTH OF PASSAGE				WIND.
			To Kingstown.		To Holyhead.		
1841.			H.	M.	H.	M.	
February	2	Zephyr	6	20	13	45	E.
	3	Otter	6	8	21	11	E.S.E.
	4	Sprightly	6	8	19	22	E. by S.
	5	Zephyr	6	30	14	55	E.S.E.
	6	Doterel	6	38	11	54	E.S.E.
	11	Zephyr...............	......		10	29	S.W. by S.
	26	Otter	11	20	5	50	N.N.E.
March	10	Doterel	13	25	6	11	
	30	Otter	11	30	6	0	S.W.
	31	Zephyr...	11	34	6	4	W.S.W. to W.
June	23	Doterel	5	50	11	0	S.W.
July	10	Otter	10	45	6	5	W.N.W.
	28	Zephyr...............	18	45	6	15	W.N.W.
September	19	Sprightly	6	30	10	55	S.S.E.
	20	Doterel	6	30	10	40	S.E.
October	12	Zephyr	10	15	6	22	N.W.N.
	14	Doterel	12	47	6	11	W.S.W.
	17	„	18	3	6	12	N.N.W. to N.W.
	19	Sprightly	11	53	6	8	S.E. to N. and N.W.
	20	Doterel	16	40	7	27	W. to W.S.W.
November	12	Sprightly	15	25	8	15	W.N.W.
	22	Doterel	10	3	5	49	N.W. by W.
	23	Zephyr..............	11	7	6	13	W. to N.W.
December	4	Otter	18	22	6	15	N.W.
	6	Sprightly	11	5	5	46	S.W. to W.
	8	Doterel	10	32	5	37	N.W.
	10	Otter	13	20	6	24	N.W.
	13	„	12	35	6	39	W.S.W. to W.
	14	Doterel	10	30	6	7	N. to N.N.W.
	15	Zephyr	12	50	6	23	W.S.W.
1842.							
January	16	„	11	48	6	19	N.W.
	22	„	10	35	6	24	S.W. to W.
	27	Sprightly	11	0	6	23	N.W.
February	10	Doterel	10	55	6	30	S.W.
	12	Otter	11	38	6	6	W.S.W.
	13	Doterel	11	30	6	49	Var. S. to W.S.W. and W.
	26	„	10	17	6	8	W.N.W.
	27	Sprightly	16	58	6	7	S.W. to W.S.W.

Experience, therefore, cannot be cited in favour of the regularity of passages to and from Holyhead.

Digitized by Google

DISTANCES AND COMPARATIVE LENGTHS OF VOYAGES.

Before stating the comparative distances of the ports, it is requisite to remark that a steamer starting from Porth-dyn-llaen would proceed direct to Kingstown, over the Kish, if after half-flood, as the Holyhead packets do at this time of tide; or she would run for the Swashway, between the Kish and Bray Bank, having four fathoms water at low water; or, she would round the north end of the Kish Bank, according to the state of the weather and the direction of the wind. To make fair allowance in comparison, and to include any objection raised to the passage, I shall take the distance round the north end of the Kish, which would make her course two degrees more to the north than if she ran direct to Kingstown.

A steamer starting from Holyhead would, in fine weather, or with favourable winds and tides, round the Platters, and then run direct for Kingstown; but in blowing weather, to avoid the race, she would run for the smooth water, between the races, a point which I am informed, by Commander Davis, is about the middle fifth part between the North Stack and the Skerries. As I have taken the course from Porth-dyn-llaen, assigned to it in unfavourable weather, I shall also take the course from Holyhead, under the same conditions, and refer to the several points on the charts, the positions of which are as follow:—

	From the Admiralty Charts.					
	North Latitude.			West Longitude.		
	°	′	″	°	′	″
Entrance to Kingstown Harbour	53	18	00	6	8	00
The Kish Light-ship	58	18	53	5	57	00
The Platters at Holyhead	53	19	30	4	37	30
The centre of the smooth water, to which steamers, in bad weather, would make to avoid the race, before shaping their course for Kingstown . .	53	22	25	4	38	40
The Sound of Porth-dyn-llaen	52	57	00	4	34	00

The respective distances would therefore be—

From the Platters at Holyhead to Kingstown . .	54.12	nautic miles.
From the Packet berth to the Platters	.78	„
Distance from the Packet berth to the entrance of Kingstown Harbour, in favourable weather .	54.90	„

From the comparative smooth water between the races at Holyhead	53.32	nautic miles.
From the Packet berth to the smooth water	3.75	,,
Distance from the Packet berth at Holyhead to Kingstown in rough weather	57.07	,,
From Porth-dyn-llaen to Kingstown, direct	60.21	,,
From Porth-dyn-llaen to the Kish Light	53.90	,,
From the Kish Light to Kingstown Harbour . . .	6.60	,,
	60.50	,,

The difference in distance will therefore be—

In fine weather . . $60.21-54.9=5.31$ nautic miles, or $6\frac{1}{4}$ statute miles.
And in rough weather . $60.5\ -57.7=2.8$,, or $3\frac{1}{3}$,,

With these distances, and the prevailing winds, an estimate may be formed of the comparative runs with vessels of certain build and power.

To arrive at the probable time required for the run across the Channel, I have referred to the experimental trip of the Princess Royal from Liverpool, the particulars of which were afforded me by Mr. Brebnor, of that town, and which I have subsequently met with in the Appendix to the Report of the Select Committee on Post Office Communication with Ireland, (27 June, 1842.) The trip was made on the 20th June, 1842. From pier-head at Kingstown to pier-head at Holyhead, the time occupied was four hours and forty-one minutes; and between the same points, on the return voyage, four hours and twenty-nine minutes; giving an average passage of four hours and thirty-five minutes. The same vessel made the voyage from Liverpool to Kingstown in eight hours and fifty-eight minutes, leaving the Clarence Dock at two minutes past seven, A.M., (19th June, 1842,) and arriving at Kingstown at four, P.M.; the Post Office packet Urgent, which started at the same time, being three hours and nineteen minutes longer in her passage to Kingstown than the Princess Royal.

The greatest speed of the Princess Alice[a] (running between Folkestone and Boulogne, a vessel of 274 tons burthen, 120 horse-power, and six feet draught) is fifteen statute miles per hour through the water; and with a steam ship of similar build, 500 tons burthen, and 240 horse-power, a speed of sixteen miles per hour may

[a] I am enabled to give this statement on the authority of Mr. Field, of the firm of Messrs. Maudslay, Sons, and Field, the builders of the engine.

Digitized by Google

be calculated on in the present state of steam machinery. A steam ship of this class would, in favourable weather, accomplish a passage in four hours, from Holyhead, sixty-four miles by the Platters, and with the average winds, in somewhat less from Porth-dyn-llaen, direct over the Kish; but as the starting of the mail trains would be arranged for passages which might generally be calculated on for certainty throughout the year, or (to insure the greatest advantage of the sea communication) for one time of starting during the summer months, and another during the winter months, to which all the arrangements for the inland branches could easily be accommodated, I shall assume an average rate of thirteen miles per hour for Holyhead, avoiding the race, which would be, on a distance of sixty-six statute miles and a half, five hours and seven minutes; and in the case of Porth-dyn-llaen, with the advantage of the winds and less strength of tide, an average rate of fourteen miles per hour, which, on the distance of seventy statute miles and a half, rounding the Kish Bank, would give for the voyage five hours and two minutes as the averages throughout the year. But as the regularity and rapidity with which the passages may be made will depend upon the build and power of the packets, and as expedition seems to be the primary consideration, steam ships of 400 horse-power should be employed, and of greater power than that in time of war.

ON THE PASSAGE OF RAILWAY TRAINS ALONG THE MENAI BRIDGE, ETC.

With regard to the effect of railway trains along the suspension bridge of the Menai, I shall briefly observe that the sectional area of the main chains being 260 square inches, and the weight of the bridge (including 130 tons additional weight due to the repairs in 1839 and 1840) 774 tons, the strain upon the main chains, on the principle used by Sir Frederick Smith and Professor Barlow, amounts to rather more than five tons per square inch, *supposing the weight to be borne equally by all the chains, and without any allowance for momentum produced by undulation*, the effects of which upon the bridge, by the gale in January, 1839, are well known.

This weight is nearly one ton sixteen cwt. per square inch more than was calculated upon in the evidence of Mr. Telford and Mr. Rennie, given before a Select Committee of the House of Commons, (29th April, 1819,) and as their calculations were with reference to iron unimpaired in its elastic force, which, after the severe trials to which the structure has been exposed, cannot be said of the chains and rods of the bridge at present, it follows that the limits intended by its engineer have been (perhaps unavoidably) considerably exceeded.

Calculations for this structure should have no reference to the ultimate strength

Digitized by Google

of the material, but to the limit of that strain upon it which, repeated year after year, would not produce an increasing tendency to injure its stability, independent of the effect of the elements and of time.

I regard the bridge as having already upon it a greater strain than I should assign to a bridge under similar circumstances;—as being very liable to an increase of that strain from the weight being unequally distributed on the suspending rods and chains;—and subject to a still greater increase from any momentum produced by undulation, the effects of which I have referred to, and which momentum must be increased by railway carriages upon it, at such a time.

A gale similar to that of January, 1839, would not probably injure the bridge to the extent which it then suffered; but it is quite certain the effects of it, even if they did not produce fracture, would considerably impair its stability.

The weight of railway carriages would be limited to one side or the other, and therefore the strain would be brought upon half the chains and suspending rods; and if a train passes without the engine, taking ten carriages at five tons each, the extra strain upon the chains would be eighty-five tons, which on 130 square inches, being equal to thirteen cwt. per square inch, would make the total strain five tons thirteen cwt. per square inch.

It may be perhaps stated, that, during the prevalence of gales of wind, the railway carriages would not cross; (and I admit it will require some management to prevent the rails being disturbed at such times;) but the great object of the government and the country being that of establishing an *uninterrupted communication with Ireland*, (to effect which so much discussion has arisen for saving a quarter of an hour by the sea voyage,) my opinion is, that the precision of this communication by *land*, and the stability of a structure of which this country may be justly proud as a great step in practical science, ought not to be risked by a course which can be avoided whichever port is adopted. These conclusions, as I have before hinted, have no reference to the ultimate strength of the material, but they depend on the effects already produced, and on the results of experiments on the material of which the bridge is formed.

OF THE EFFECT OF ANY BRIDGE OVER THE MENAI ON THE NAVIGATION.

The effect of any projected bridge upon the navigation of the Menai Strait would depend altogether upon the design and the arrangements connected with it.

The impediments to the passage of vessels between Caernarvon Bar and Beaumaris are such, that in this distance three pilots are required. The entire removal of the Swelly Rocks, and others which obstruct the passage, would considerably in-

Digitized by Google

crease the traffic through the Strait, would act beneficially on Caernarvon Bar, and *might* compensate for the obstruction which the piers of a bridge of large span would produce. Practically speaking, however, it must be observed that the construction of any bridge would be attended with great difficulties and expense—would be subject to great delay; and if time is an object in accomplishing the projected improvement in the communication with Ireland, a new bridge over the Menai is not very consistent with that object.

ON THE RAILWAYS WHICH MAY CONNECT THE SELECTED PORT WITH THE METROPOLIS, AND THE TIME OCCUPIED IN THE TRANSMISSION OF THE MAILS.

The investigations of the Irish Railway Commissioners, of Sir Frederick Smith and Professor Barlow, including the Reports of the engineers of the lines proposed, have furnished sufficient data for a conclusion on the points in this part of the enquiry.

The results arrived at by the Railway Commissioners, respecting the lines from London to Holyhead and to Porth-dyn-llaen, and from thence by steam to Kingstown, are as follow, allowing—

Thirty minutes from the Post Office in London to starting on the railway.

Thirty minutes from the railway to embark and sail, a rate of twenty-seven miles per hour by railway, including stoppages, and ten miles per hour for the voyage.

		Time by Railway.		Length of Voyage.	Time on Voyage 30′ for embarking and sailing.		Inland Time.	
	Miles.	H.	M.	Miles.	H.	M.	H.	M.
Holyhead Line .	272	10	35	63	6	48	17	23
Porth-dyn-llaen .	260	10	8	70	7	30	17	38

Making a difference of fifteen minutes, without allowing for the delay in passing the Menai Bridge, or for the effect of more favourable winds in the passage between Porth-dyn-llaen and Kingstown. If the fifteen minutes (allowed by Sir Frederick Smith and Professor Barlow) for the delay at the Menai Bridge be added to the seventeen hours twenty-three minutes, the time occupied in each line from London to Dublin would be the same.

The Commissioners, although they state that "the voyage from Porth-dyn-llaen

Digitized by Google

would be shorter and more favourable in direction," have not, in their calculation, estimated any saving of time in the voyage on that account.

Mr. Cubitt, whose calculations are referred to in the same Report as corroborative of the conclusions of the Commissioners, estimated the time for performing the journey between London and Dublin by Porth-dyn-llaen and by Holyhead *as equal*, stating his opinion that "the former was in the best position of any for a passage between England and Kingstown Harbour."

The difference in any results depends upon the speed assumed; but leaving passenger trains out of the calculation, I shall take for the mail trains a speed on the existing lines which has been attained, and for any extension of those lines, a speed of which the application of the atmospheric principle will justify the expectation. Having witnessed the experiments at Wormwood Scrubs, I was prepared for a result highly creditable to the talents of Messrs. Clegg and Samuda, and to the energetic exertions of Mr. Pim, but not to the full extent which has been realized. Should the valve fully answer when in constant work, (and it will be tried more at Kingstown than on a principal line,) the advantages of the atmospheric system may be regarded as certain.

The velocity attainable with safety will be considerably beyond that which can be so attained by the locomotive; the limit of that velocity, and of the weight to be moved, depending on the size of the air pump and the diameter of the tube.

The inclination of the ascending planes is no impediment to its progress, causing only a temporary diminution of speed. To these advantages may be added the saving of the weight of the locomotive, and the impossibility of collision.

It offers, therefore, facilities for traversing, at a high speed, countries over which a railway with locomotive power throughout would be impracticable.

In calculating the rate at which the mail trains may be run as practicable, under strict regulations, 35 miles per hour may be taken on the Birmingham and Grand Junction lines; 40 miles per hour on the Great Western; and 50 miles per hour by the atmospheric, supposing that principle adopted from Didcot in one case, and from Chester in another: the distances and times may then be reckoned as in the following Table.

Digitized by Google

	Distance in Miles.	Speed by Locomotive Power in Miles per Hour.	Speed by Atmospheric Power, in Miles per Hour.	Time by Locomotive Power for the whole Distances.	Time by Locomotive Power to Didcot in the first case, to Chester in the second and third cases.	Time by Atmospheric Power from Didcot to Porth-dyn-llaen in the first case, from Chester to Porth-dyn-llaen in the second case, and from Chester to Holyhead in the third case.	Stoppages by the way, including in the third case 15 minutes for crossing the Menai Bridge.	Total Time by Locomotive and Atmospheric Power to Porth-dyn-llaen in the first case *viâ* Worcester, in the second case *viâ* Chester, and to Holyhead in the third case.	Time by Steamer to Kingstown from Porth-dyn-llaen or Holyhead.	Time lost embarking and landing Mails and Conveyances to the Dublin Post Office.	Total Time performing Journey between London and the Dublin Post Office, Atmospheric and Locomotive Power and Steamers.	Total Time performing Journey between London and the Dublin Post Office, using Locomotive power for the whole distance from London to the Port of Embarkation.
				H. M.	H. M.	H. M.	H. M.	H. M.	H. H.	H. M.	H. M.	H. M.
I. From London to Porth-dyn-llaen by Mr. Brunel's broad gauge line, *viâ* Worcester, and proceeding by Dolgelly and Tremadock. According to the Report of Sir Frederick Smith and Professor Barlow.	260½	[a] 40	50	6 31	1 19	4 10	0 40	6 9	5 0	0 44	11 53	12 55
II. From London to Porth-dyn-llaen *viâ* Chester, according to the Report of Sir Frederick Smith and Professor Barlow, deducting five miles, which Mr. Walker has suggested may be saved by deviations of existing lines.	269.76[c]	[b] 36	50	7 30	5 2	1 46	0 43	7 28	5 0	0 44	13 12	13 54
III. From London to Holyhead *viâ* Chester and the Menai Bridge, according to the Report of Sir Frederick Smith and Professor Barlow, deducting five miles, which Mr. Walker has suggested may be saved by deviations of existing lines.	267	[b] 36	50	7 25	5 2	1 41	0 55	7 38	5 0	0 44	13 22	14 4

[a] Deduced from performance of Great Western engines.

[b] Deduced from performance of engines on narrow gauge lines.

Digitized by Google

It will be seen that the advantages of transit, as they relate to time, are in favour of the route to Porth-dyn-llaen, *viâ* Didcot, Worcester, Dolgelly, Tremadoc, &c.

The above calculations are with reference to a high rate of speed consequent upon the importance attached to the rapidity of communication between the two countries, although the present arrangements for the transmission of the mails are not such as to warrant the conclusion that half an hour is of any consequence. The mails leaving London at the usual hour, would arrive in Dublin at 9 A.M. These letters could not be answered in time for useful delivery on the same day, and there would be no object, in a commercial point of view, attainable by the mail returning within three or four hours after that time, as the letters would not be delivered in London until midnight; but a mail might leave each place at eight in the morning and at eight in the evening, by which arrangement all commercial purposes would be attainable. On this assumption, half an hour cannot be of great importance in the transit.

But *for the purposes of the Government* the case is very different, and to meet exigencies of political importance, I have devoted some time and thought, though the subject formed no part of your instructions. A system of signals by ships stationed across the Channel, if practicable, would continue a telegraphic communication between the two capitals; but if this is not attainable, the electric telegraph will convey communications by land, and from the adopted port for the packets, by one of the mail steamers, Government intelligence could be conveyed in less than 4½ hours.

The whole cost of this communication, to the importance of which no numerical value can be assigned, would be under £200 per mile, or for the whole distance by land between London and Dublin, under £54,000.

Although not strictly appertaining to my department, it is not irrelevant to remark upon the influence of the selection of either of the ports and lines of railways upon the districts interested, and the public accommodation. The importance of providing for competing lines of railway, and thus securing the public benefit, with due regard to the interests of the proprietors of these undertakings, appears to be an object worthy of an enlightened legislature. With this view are made the remarks in the Third Report from the Select Committee on Railways, that "the power of encouraging, or, if need be, of creating competition, even although the remedy thus to be supplied might be partial, and must be costly, is nevertheless an engine of great capabilities in the hands of the state, and one which might be used to practical advantage in any case in which railways realizing very large profits should manifest a

Digitized by Google

disposition to deal illiberally by the public;"[a] and the observations of the Premier himself, that "the true interests of society will best be protected by holding over them the checks of competition, and of the improvement that may take place in science," are in the same spirit[b].

In the present case, while the Holyhead line would shut out the practicability of competition, the adoption of the coast line to Porth-dyn-llaen by Bangor and Caernarvon would allow of the continuation of the Great Western line from Worcester, through the centre of North Wales, to that port; thus opening between the metropolis and this port (if selected for Ireland) two railways, the Great Western and the Birmingham, which should embrace the greatest number of passengers and amount of traffic attainable, and at the same time open out that portion of the country, the resources of which are much greater in comparison than the other.

In concluding this Report, I would beg leave to observe, that I have not deemed it within my province to notice in detail the extraordinary, and, to me, unaccountable statements and opinions, respecting the two ports which have come under my notice in the printed documents during this inquiry. For the same reason, also, I forbear to append to my Report, letters which I have received from parties upon the subject, and the general tenor of which is opposed to the adoption of Holyhead. It is evident that documents of this description may be congregated *ad infinitum* without advancing a single step towards a conclusion, more especially as practical means of solving any doubt are easily attainable; and as the only reasonable doubt which can exist as to the fitness of Porth-dyn-llaen for a packet station consists in the estimated time for performing the voyage, I would earnestly recommend that this should be set at rest by running a steamer of approved build and power between that place and Kingstown. A few trials of this description would have been more convincing to the public department interested in the result, than probably all the opinions which have been given on that branch of the subject; and until such trials shall be properly made, it is evident that the most important practical proof will be wanting in arriving at a conclusion.

Upon other points of the inquiry, although I have endeavoured to treat them explicitly in this Report, yet to avoid any misconception, I will ask permission to embody my opinions in a few words:

1. That Porth-dyn-llaen, whether with reference to position, natural capabilities, or economy in constructing works, is preferable to Holyhead as a harbour of refuge.

[a] Third Report from the Select Committee on Railways, 1 April, 1844.

[b] Speech of Sir Robert Peel, 5 February, 1844.

Digitized by Google

2. That the surveys of Holyhead Bay by Mr. Thomas, R.N., in 1816, and Captain Beechey, R.N., in 1840, afford evidence of the accumulation of drift on the proposed site of the harbour of refuge at Holyhead, and also of drift or detritus from the River Alaw on the southern shore; and that it is essential to determine by geological investigation the proportion of the accumulation due to the drift from the sea and to the detritus from the Alaw, and what effects the causes of this accumulation will have on the depth of water in any proposed harbour in Holyhead Bay.

3. That although there is no appearance of any drift at Porth-dyn-llaen, and the sweep of the ebb tide is favourable for maintaining a regular depth of water, the difference in one of the soundings on Lewis Morris's charts, and that of Commander Sheringham, should be further investigated.

4. That although Holyhead is from three to five and one-third nautic miles (according to the course taken) nearer to Kingstown than Porth-dyn-llaen is, yet the more favourable course from the latter, with relation to the prevailing winds and to the tides, warrants the conclusion that the passage to and from that port and Kingstown Harbour would be performed in less time, *on the average*, than it would be between Kingstown and Holyhead, but that it is essential that well conducted experimental passages between the two ports be made.

5. That the strain on the Menai Bridge is already greater than was intended by its engineer, and greater than it is advisable to assign to the bridge, considering its construction and exposed position; that this strain is liable to be considerably increased by unequal bearing, and that the passage of connected railway trains would be injurious to the general stability of the bridge.

6. That by the removal of the Swelly Rocks, advantages considerably more than adequate to the expense would be derived to the navigation of the Menai Straits and to the entrance over Caernarvon Bar; and this proceeding might compensate for the obstruction consequent on constructing a new bridge, but that the difficulty and expense attending the construction of such a bridge would be very great, and the time required not consistent with the intended object of communication.

7. That by the known means of railway transit by land, and powerful steamers by sea, the communication between London and Dublin can be effected in twelve hours; and by the same steamers and the means in use for communications by the *electric telegraph, intelligence between the two capitals can be conveyed within five hours.*

Lastly, That from the importance of the whole subject, whether with relation to a harbour of refuge, or to the communication between London and Dublin, the further

Digitized by Google

investigation and experimental passages before referred to are required before a harbour and packet station, at either port, should be determined on.

I have the honour to be, my Lords and Gentlemen,
Your obedient Servant,
(Signed) THOMAS PAGE.

To the Right Honourable the Earl of Powis, and the other Members of the Committee of Noblemen and Gentlemen promoting the best line of communication between London and Dublin.

TABLE I.

Of the Direction and Force of the Wind, and Number of Days during which each Wind prevailed in the Years 1841, 1842, and 1843, from the Register of Observations kept at Holyhead; showing how they may affect the Passages between Kingstown and Holyhead.

Note.—The Number of days is the sum of the three years, and the force of the Wind is the mean force, found by dividing the sum of the forces each day, by the number of days.

Beam Winds, and Two Points before and Two Points abaft the Beam, taken as favourable Winds for a regular passage both ways.

Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.	Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.
With the Flood:			With the Ebb:		
S.S.W.	39	64 × 4.82 = 308.48	N.N.W.	29	41 × 4.21 = 172.61
S. by W.	......	7 × 3.20 = 22.40	N. by W.	......	8 × 5.47 = 43.76
S.	34	15 × 4.99 = 74.85	N.	36	33 × 3.9 = 128.7
S. by E.	....	7 × 5.20 = 36.40	N. by E.	......	15 × 3.52 = 52.80
S.S.E.	15	17 × 4.70 = 79.90	N.N.E.	24	58 × 4.02 = 233.16
		522.03			631.03

Digitized by Google

TABLE I.—*continued.*

Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.	Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.
Winds available for both Passages, but more for Kingstown.					
With the Flood:			With the Ebb:		
S.W. by S.	......	30 × 5. = 150.	N.W. by N.	....	15 × 5.84 = 87.60
S.W.	122	159 × 4.23 = 672.57	N.W.	43	54 × 5.39 = 291.06
		822.57			378.66
Winds available for both Passages, but more for Holyhead.					
With the Flood:			With the Ebb:		
S.E. by S.	......	1 × 5.00 = 5.	N.E. by N.	....	9 × 3.40 = 30.60
S.E.	68	14 × 4.20 = 58.80	N.E.	32	41 × 3.16 = 129.56
		63.80			160.16
On the Bow against Kingstown and on the Quarter for Holyhead.					
With the Flood:			With the Ebb:		
S.W. by W.	....	44 × 5.07 = 223.08	N.W. by W.	......	15 × 4.50 = 67.50
W.S.W.	37	155 × 4.5 = 517.5	N.W.	43	54 × 5.39 = 291.06
		740.58			358.56
On the Bow against Holyhead and on the Quarter for Kingstown.					
With the Flood:			With the Ebb:		
S.E. by E.	....	2 × 3.00 = 6.00	N.E. by E.	......	6 × 5.55 = 33.30
E.S.E.	25	26 × 4.73 = 122.98	E.N.E.	27	38 × 3.75 = 142.50
		128.98			175.80

Digitized by Google

TABLE I.—*continued.*

Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.
Head Winds against Kingstown, and aft for Holyhead.		
W. by S.	......	34 × 5.58 = 189.72
W.	68	30 × 4.55 = 136.50
W. by N.	......	12 × 5.53 = 66.36
		392.58
Head Winds against Holyhead, and aft for Kingstown.		
E. by S.	......	30 × 5.70 = 171.
E.	56	36 × 4.13 = 148.68
E. by N.	......	12 × 3.75 = 45.00
		364.68

TABLE II.

OF the DIRECTION and FORCE of the WIND, and Number of Days during which each Wind prevailed in the Years 1841, 1842, and 1843, from the Register of Observations kept at Holyhead, and returned to Liverpool by Telegraph; showing how they may affect the Passages between Kingston and Porth-dyn-llaen.

Note.—The Number of days is the sum of the three years, and the force of the Wind is the mean force, found by dividing the sum of the forces each day by the number of days.

Beam Winds, and Two Points before and Two Points abaft the Beam, taken as the most favourable Winds for a regular Passage each way.

Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.	Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.
With the Flood:			With the Ebb:		
S.W.	122	159 × 4.23 = 672.57	N.E.	32	41 × 3.16 = 129.56
S.W. by S.	......	30 × 5.00 = 150.00	N.E. by N.	......	9 × 3.40 = 30.60
S.S.W.	39	64 × 4.82 = 308.48	N.N.E.	24	58 × 4.02 = 233.16
S. by W.	......	7 × 3.20 = 22.40	N. by E.	......	15 × 3.52 = 52.80
S.	34	15 × 5. = 74.85	N.	36	33 × 3.9 = 128.7
		1228.30			574.82

Digitized by Google

TABLE II.—*continued.*

Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.	Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.
Winds available for both Passages, but more for Kingstown.					
With the Flood:			With the Ebb:		
S. by E.	......	7 × 5.20 = 36.40	N.E. by E.	......	6 × 5.55 = 33.30
S.S.E.	15	17 × 4.70 = 79.90	E.N.E.	27	38 × 3.75 = 142.50
		116.30			175.80
Winds available for both Passages, but more for Porth-dyn-llaen.					
With the Flood:			With the Ebb:		
S.W. by W.	......	44 × 5.07 = 223.08	N. by W.	......	8 × 5.47 = 43.76
W.S.W.	37	155 × 4.5 = 517.5	N.N.W.	29	41 × 4.21 = 172.61
		740.58			216.37
On the Bow against Kingstown, and on the Quarter for Porth-dyn-llaen.					
With the Flood:			With the Ebb:		
W. by S.	......	34 × 5.58 = 189.72	N.W. by N.	......	15 × 5.84 = 87.60
W.	68	30 × 4.55 = 136.50	N.W.	43	54 × 5.39 = 291.06
		326.22			378.66
On the Bow against Porth-dyn-llaen, and on the Quarter for Kingstown.					
With the Flood:			With the Ebb:		
S.E. by S.	......	1 × 5.0 = 5.00	E. by N.	......	12 × 3.75 = 45.00
S.E.	68	14 × 4.20 = 58.80	E.	56	36 × 4.13 = 148.68
		63.80			193.68

Digitized by Google

TABLE II.—*continued.*

Winds.	Days in 1839 and 1840.	Days and Mean Force in 1841, 2, 3.
Head Winds against Porth-dyn-llaen, and aft for Kingstown.		
E. by S.	……	$30 \times 5.70 = 171.00$
E.S.E.	25	$26 \times 4.73 = 122.98$
S.E. by E.	……	$2 \times 3.00 = 6.00$
		299.98
Head Winds against Kingstown, and aft for Porth-dyn-llaen.		
W. by N.	……	$12 \times 5.53 = 65.36$
W.N.W.	69	$45 \times 4.83 = 217.35$
N.W. by W.	……	$15 \times 4.50 = 67.50$
		350.21

ABSTRACT of the NUMBER of DAYS, DIRECTION and STRENGTH of the WINDS, taken from the Register of the Royal Observatory at Greenwich, for each of the Years 1837, 1838, 1839, and 1840, viz.:

	West.		South West.		North West.		East.		South East.		North East.		South.		North.	
	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.
1837.																
January …..	1½	1.00	13½	3.93	2	3.50	0½	4.00	1½	4.50	6	3.58	4	3.87	2	2.25
February …	0½	6.00	12	4.54	2	6.00	2½	1.60	4½	1.89	0	0.00	4½	6.22	2	4.50
March …….	2	3.50	4½	4.77	4½	4.11	0½	2.00	1½	1.67	11½	3.83	1½	5.00	5	4.70
April ……..	1	3.00	8	4.00	8	3.56	1½	3.00	1½	3.00	6	6.00	2	2.75	2	3.00
May ………	1	5.00	10	3.25	3½	3.86	1½	1.66	0½	2.00	6	3.50	1	2.00	7½	4.87
June………	1	3.50	10½	3.43	3	4.00	7	3.64	0½	2.00	5½	3.55	2	3.00	0½	3.00
July ………	1½	3.33	12½	3.92	4½	3.00	2	3.00	0½	2.00	6	2.92	0½	8.00	3½	2.57
August ……	2½	2.60	10½	3.52	1	2.50	2½	2.20	1½	2.00	8	2.87	3	4.00	2	4.50
September..	3	3.50	8½	3.82	1	5.00	4	3.50	1½	1.67	8	3.00	1½	3.33	2½	3.00
October……	5½	3.00	18½	2.54	1½	2.00	0	0.00	0	0.00	2	2.75	2	3.50	1½	4.67
November..	3	4.00	15½	4.23	4½	3.22	1	1.50	0	0.00	1	1.50	1	3.00	4	3.11
December…	1½	2.00	10	3.80	0½	4.00	1	1.00	6	2.08	6	2.58	4	2.50	2	3.50
	24	3.37	134	3.81	36	3.69	24	2.46	19½	2.28	66	3.28	27	3.93	34½	3.64

Digitized by Google

ABSTRACT—*continued.*

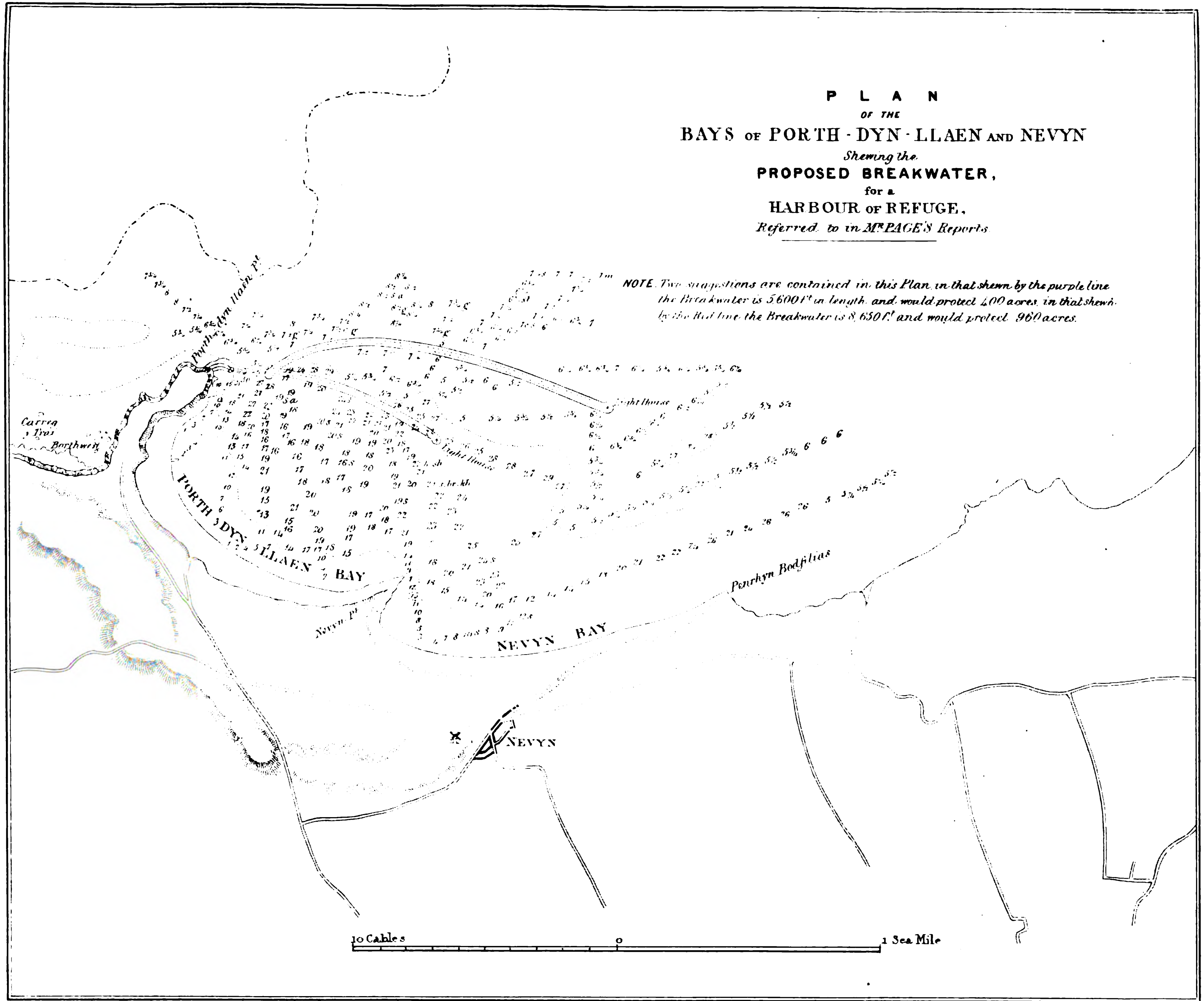
	West.		South West.		North West.		East.		South East.		North East.		South.		North.	
	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.
1838.																
January.....	1	1.50	3	2.50	0	0.00	3	5.17	3	2.67	14	4.07	4	3.62	3	2.50
February....	0½	1.00	3½	5.14	0	0.00	8	4.00	2	2.00	8	2.75	2½	4.60	3½	3.57
March	3½	4.43	7	4.29	6½	4.38	3	1.67	4½	2.67	3	2.33	0½	3.00	3	2.83
April	5½	3.00	4½	4.22	8½	4.94	1	3.00	0½	2.00	0½	7.00	1½	3.00	8	5.00
May	0	0.00	5	3.60	2½	3.60	3½	3.29	1½	4.00	7½	3.20	4	3.75	7	3.57
June.........	1	3.50	15½	3.48	2½	3.60	1	3.00	2	2.25	1	2.00	5	2.90	2	3.75
July	4½	2.78	13½	3.55	3½	3.86	0	0.00	3	1.67	0	0.00	3	1.83	3½	4.00
August	3	3.50	16½	4.39	8½	4.53	0	0.00	0	0.00	0	0.00	2½	5.20	0½	8.00
September..	4½	1.89	8½	1.94	0½	3.00	0½	2.00	0½	2.00	7½	1.80	4½	1.44	3½	2.71
October	3½	5.71	10½	4.09	4	4.62	0	0.00	0	0.00	7½	3.00	3½	1.71	2	3.50
November..	1	2.00	10½	3.57	1	2.50	2½	4.60	1½	6.67	11½	2.74	0½	2.00	1½	3.00
December...	5½	2.09	9½	3.47	4	2.75	2½	1.80	4	1.87	2½	2.20	2½	3.00	0½	4.00
	33½	2.67	107½	3.69	41½	3.78	25	3.17	22½	2.78	63	3.11	34	3.05	38	3.87
1839.																
January.....	5	3.30	11	5.14	7	4.50	0	0.00	0½	4.00	2½	4.60	0½	2.00	4½	3.67
February ...	5½	2.73	10½	3.62	4	2.75	0½	3.00	2½	2.60	2½	4.00	2½	2.20	0	0.00
March	2	2.50	3½	2.71	4½	3.44	2½	3.40	0	0.00	10½	4.43	0	0.00	8	5.25
April	0	0.00	6	3.58	3	4.33	2½	2.40	0½	2.00	11½	4.08	2	3.00	4½	4.78
May	0	0.00	5½	2.45	4	4.00	1½	2.00	1	2.50	9	4.94	2	2.50	8	4.62
June.........	1½	5.00	10	3.40	2	6.00	3½	3.43	1½	2.67	6	3.17	4½	5.11	1	2.50
July..........	0	0.00	15½	4.09	2½	2.80	0½	5.00	3	3.67	2	2.00	5½	5.09	2	3.00
August	3½	2.86	10	3.65	5	2.90	0	0.00	1	2.00	0½	2.00	5½	2.73	5½	2.45
September..	4	2.75	15	4.37	0½	2.00	0½	2.00	3	3.33	0½	2.00	6½	3.23	0	0.00
October	0½	1.00	4	2.75	0½	2.00	2½	1.60	5	2.20	9	4.61	7	2.86	2½	5.20
November..	1	1.00	9½	2.26	2	3.25	4½	3.00	7	2.36	3½	3.43	2½	1.80	0	0.00
December...	2	2.00	9½	3.26	1½	2.33	5	2.50	5	3.00	3½	1.71	3½	2.28	1	2.00
	25	2.57	110	3.44	36½	3.36	23½	2.83	30	2.76	61	3.36	42	2.98	37	3.72
1840.																
January.....	3½	4.00	13½	5.50	0½	4.00	2	2.00	0½	3.00	4	2.25	6	4.00	1	2.00
February ...	1	4.50	9	3.83	0½	5.00	6½	4.15	1	4.50	6½	4.08	4½	4.43	0	0.00
March	2	2.50	3½	2.71	4½	3.44	2½	3.40	0	0.00	11	4.36	0	0.00	7½	5.40
April	3	2.17	5	2.00	2½	2.40	4	2.00	1	2.00	7	3.14	2	2.50	5½	4.18
May	1½	2.67	13½	3.44	2	4.25	2½	3.20	1½	2.00	3½	3.14	2	3.25	4½	4.47
June.........	3	3.00	15½	4.07	6½	4.31	0½	3.00	1½	3.00	0	0.00	3	2.83	0	0.00
July	8½	4.12	13	4.11	6	3.75	0	0.00	0	0.00	1	2.00	0½	4.00	2	2.75
August	7½	3.93	12½	3.20	0½	2.00	4	2.88	1½	2.33	3	2.83	1	6.00	1	1.50
September..	8½	3.05	12½	3.20	3½	2.57	0	0.00	0½	3.00	1½	3.00	1	4.00	2½	5.20
October	5	1.80	5½	2.36	7½	3.40	1½	1.67	1½	2.33	7½	2.29	1	4.00	1½	3.00
November..	2	3.75	12½	4.48	2	2.50	5½	2.00	2½	4.00	2	2.75	2	3.25	1½	3.66
December...	2½	2.00	6½	2.23	2½	2.40	7½	3.00	1½	1.33	7½	1.46	1½	1.33	1½	2.33
	48	3.12	122½	3.43	38½	3.34	36½	2.73	13	2.75	54½	2.85	24½	3.59	28½	3.48

Digitized by Google

The General Abstract of the Number of Days, Direction, and Strength of the Winds, taken from the Register of the Royal Observatory at Greenwich, for the Years 1837, 1838, 1839, and 1840, viz.:

	West.		South West.		North West.		East.		South East.		North East.		South.		North.	
	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.	Days.	Average Strength.
1837.........	24	3.37	134	3.81	36	3.69	24	2.46	19½	2.28	66	3.28	27	3.93	34½	3.64
1838........	33½	2.67	107½	3.69	41½	3.78	25	3.17	22½	2.78	63	3.11	34	3.05	38	3.87
1839.........	25	2.57	110	3.44	36½	3.36	23½	2.83	30	2.76	61	3.36	42	2.98	37	3.72
1840.........	48	3.12	122½	3.43	38½	3.34	36½	2.73	13	2.75	54½	2.85	24½	3.59	28½	3.48
	130½	2.93	474	3.59	152½	3.54	109	2.79	85	2.64	244½	3.15	127½	3.39	138	3.68

Digitized by Google



Digitized by Google

DESCRIPTION OF A MODEL PLAN

FOR THE CONSTRUCTION OF A SPACIOUS

HARBOUR IN CONNEXION WITH THE GRANTON PIER,

By increasing the velocity of the tidal waters on the south shore, "equivalent to that on the north of the Frith of Forth," in the immediate vicinity of the Granton works, by a series of arches, as the most effectual means of removing all silt and deposit from the pier and proposed harbour, and for affording a port of refuge to the shipping on the east coast when driven into the Frith by winds and tempests, and for general trade.

By J. D. BOSWALL, Captain R. N.

It is well known to mariners that the tides in this navigable estuary run very differently in respect to velocity and duration; for instance, on the north and south shores, owing to the obstructions of islands, headlands, and shallows, with the land streams meeting the currents of the sea in passing the coasts of Fife and Forfar on the north side, and the Lothians and Berwick on the south, the flood of the tide sets up six hours, the neap tides for five hours, and the ebb tides run for six hours and six hours respectively, at the rates of 2½ and 3½ miles per hour, according to the quantity of fresh water discharged by the rivers. This united current sets in the direction of s.w.½w., s.w. by w., w.s.w., and w.s.w.½w., up to Eli-Ness into Largo and Kirkaldy Bays, at 3¾ miles per hour, to the gorge or overfalls at Inchkeith, where the velocity of the tide is checked to 3½ miles per hour, rounding Kinghorn Sands into Burntisland Bay, which has proved more than sufficient to prevent any sand, silt, or deposit near the new pier. As these works have progressed, the depth of water has increased over clear blue clay—a result not anticipated by the contractors, but of great consequence to the public-spirited promoters of this great national ferry at Burntisland.

On the south shore, the tide runs during flood from 3 to 3½ hours only, being constantly influenced by winds and the state of the weather in the North Seas, and tides

Digitized by Google

on the coast of England crossing the entrance of the Forth and Tay; but after passing the Bass and Fedra Islands, from a W.½N. to a S.W.½W. course, the flood is retarded by sands and rocks from Gullen-Ness, extending all the way to Musselburgh, first at a velocity of two miles per hour, from the Bass to Aberlady Bay, passing Cockenzie Harbour. "From the judicious construction of this snug little port, the natural course of the tides has been consulted, not obstructed, as elsewhere; no sand or deposit ventures into it."

Over Musselburgh sands the tidal stream runs one mile and a half per hour; and by the report of William Chapman in 1824, that eminent and practical engineer states, that the set of the flood tide over Leith sands is one mile per hour, but the principal strength of the flood runs up to the northward of the Black Rocks. His plan and extension of the Leith Pier has been progressing seaward since 1826, and, by the operations of closing up the passage between the present end of the pier and Martello Tower, an increased velocity of the flood (since Chapman's Report) is now going on outside the Black Rocks, and is acting with considerable effect along the whole line of the shore to low-water mark; and outside of this line, by scouring and deepening the shore opposite Newhaven as far westward as the east side of Granton Pier—which has now a greater depth of water alongside the wharfs and slips than on the west side, as ascertained at a very low tide on the 2nd of July last. On reference to the survey in 1834, there was depth of water off the outward points of the Oxcraigs, 6 feet 5 inches, and 8 feet 3 inches on each side, the bottom clear blue clay.

The ebb tide runs during nine hours with a velocity of two and three miles per hour, as it may be affected by the rivers and tributary streams, the ebb thus exceeding flood by twelve hours during the twenty-four in duration, and about a mile an hour in velocity. This will explain the set of the tides known to seamen by the terms tide and half tides, very common in narrow waters where inlets and bays exist, as on the coasts of the Forth.

The course of the ebb is also checked and altered by the Buchan, Cramond, and Bernie Rocks, 1300 feet long, 1¼ mile from the Oxcraig, including the Drum and Cramond sands, all to the westward of Granton Pier. These formidable obstructions seriously affect the ebb; it becomes sluggish, the velocity scarcely half a mile per hour in-shore, and ceases altogether, leaving dry these sands and rocks of great extent northward, by compass bearings, nearly covering the whole length of Granton Pier, and on which the mud and scourings of the land streams continue to float on the surface of the harder bank, forming, as may be seen at low-water springs, small nuclei of sands and shoals, as the tidal current of greater strength in freshes directs them into still water, where they form deposit. The extension of the Drum Sand

Digitized by Google

northward was ascertained by one of the Stirling steam boats. She was going her usual course in the fair-way channel up to the Queensferry, but the crew were surprised to find themselves aground, when they supposed they were in twelve feet water low tide.

There is also a portion of sand and deposit from another quarter: when about the top of high water in Inverkeithing Bay, the ebb has commenced above the Ferries, and soon joins the great breadth of waters—the deepest in the Forth, thirty-two fathoms—and, guided by the promontory of the Carlin's Nose, at the North Ferry, the current of the flood rushes across the strait, incorporates with the ebb passing downwards between Cramond and Mickery Islands, spreading over the Drum Sands, Granton, and Newhaven shores, where Leith Sands, at a higher elevation, turns the tidal current off in a northerly direction, and meets the sea at change of tide.

The vicinity of the river Almond, so near the Granton Pier, is to be regretted; but there is every confidence that this river and the Drum Sands may be rendered harmless by the plan now submitted, if once fairly investigated by competent and practical persons.

This river rises in Lanarkshire, and pursuing its northerly course for forty miles, through an agricultural country, where a general and extensive drainage has taken place, carries along with its dark and rapid stream, quantities of earthy substances, which are deposited on the sands in Cramond Bay. Much of the diluvian is constantly disturbed, by the action of the sea, in north and westerly winds, and will rise and float from the bottom of the harder sand-bank in any direction, by every current, eddy tides, or land streams, whichever prevails, "from the Hound Point, and numerous still-water inlets inside the Black Rocks, Lyal, and Granton Bushes, within a mile of Granton Pier;" and, from present appearances, an expensive dredging operation will soon be necessary to remove the mud and deposit now accumulating on the west side at the steam packet wharfs.

It is hoped that, from the above facts, "and by evidence before a select committee of the House of Commons on Leith and Newhaven Harbours, 1835," it is clearly demonstrated, that the tides are too weak and irregular to accumulate and supply back-water for sluicing and cleaning harbours anywhere within the Frith of Forth.

The improvements of Leith Harbour, by this and other projects, begun with Mr. Wentworth, engineer, in 1786, and now under the superintendence of commissioners who may be disposed to investigate the application of openings through which slack tidal waters, "so much against the improvement of the port," may acquire sufficient

Digitized by Google

velocity to carry off silt and deposit, and if satisfied of the principle, adopt for the farther extension of their east pier into twelve feet low water.

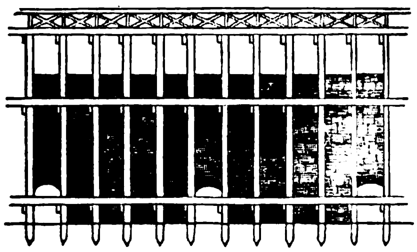
The use of arches or openings in marine architecture, is not a new idea,—it is exemplified by the ports and harbours in the Mediterranean, and are still, for the purposes of commerce, superior to many for local trade as well as foreign, as Genoa, the Harbour of Spittiza, Gulf of Pisa, Ostia, entrance to the Tiber, part of the Port of Leghorn, and the ruins by earthquake of a station of the Roman fleet and galleys in the Bay of Biaja, and that under Cape Masinium. The object of these ancient works was to increase the force of currents, and prevent their porti and moli from sanding up, as the winds in those seas greatly influence their velocity from one to three miles per hour. The proposed plan will be found less expensive at the end of its completion, if fairly estimated by the price of materials required for its construction, all at low figures in the market. With the assistance of the diving-bell and helmet for the deeper water and tide work, it is much cheaper and quicker than the old system of cofferdam,—securing a safe harbour of refuge,—giving additional accommodation for steam, and the general trade of the Forth,—affording deeper water at all times of tide,—and a link of the chain by sea with all the railways, not only connected with Scotland, but to the south,—and west parts of the United Kingdom.

The area of the proposed harbour will contain 111,993,000 cubic feet of tidal water; and by the chart of 1834, at an ordinary spring tide, there will be 16 feet 6 inches—"datum, the level of the dock silt, Leith;" and at neap tides, an average depth of 11 feet, containing 85,520,400 cubic feet of tidal water, inclosed by (A) Granton Pier and wharfs on the west, 1700 feet in length. (B) A breakwater pier with arches, on the northern face, 2280 feet in length. (C) Second breakwater pier, the arches commencing, at low-water spring tides, on the eastern face, 1830 feet in length. "Advantage may be taken of the inner section of the east breakwater pier to place one or two under-shot water wheels, on which the flood and ebb will act in producing rotary power for machinery, applicable to many important uses, and superseding smoke or steam furnaces." An opening, or eastern entrance, bearing E. by N., and W. by S., the straight course up or down the Forth, 200 feet wide (D). "No difficulty in taking or leaving the harbour," and an extensive south-western quay wall (F), 2500 feet in length, connecting the two piers on the land side of the harbour. If this wall was founded 12 feet deep from the present surface of the beach, and excavated to 10 feet deep, as the height of the neap tides on the north side at low water, at every ordinary spring tide there will be within the harbour 26 feet 6 inches in depth, and 93½ imperial acres of water covering it; and at neap tides,

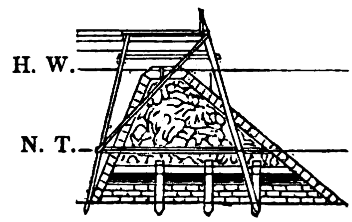
Digitized by Google

30 imperial acres of water; and very low tides, not less than 8 feet water at all times.

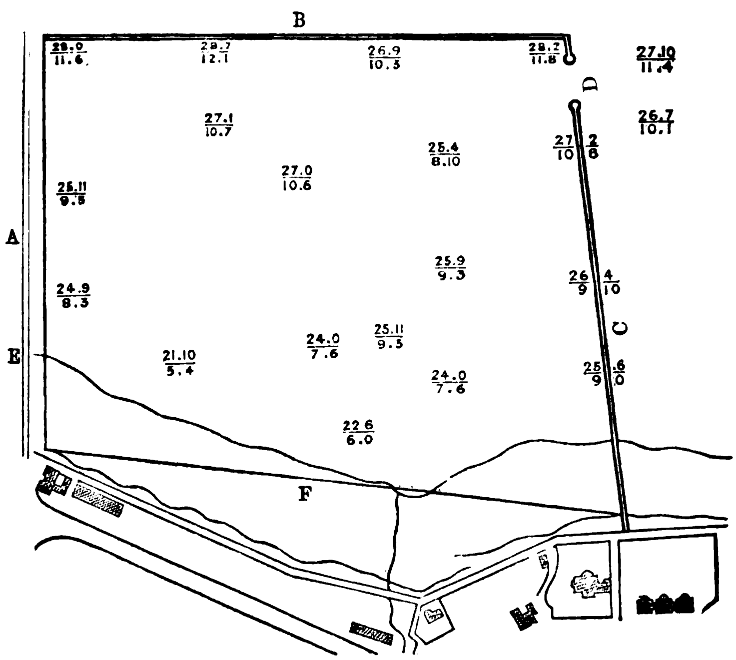
Inside Elevation of N. and S. Piers.



Profile of N. and S. Breakwater.



HARBOUR.



Provided the following suggestion was gone into by those interested, to re-open, under the Granton Pier, at E, the natural passage between the Oxcraig Rocks, once 30 feet wide, where the tide did pass at a velocity, during springs, two miles an hour through this ancient boat passage, well known, and taken by the oyster fishermen at half tide, in taking a short and smooth water cut in southerly winds. There was no silt or deposit in this channel, but seven feet water over a clear sand and gravelly

Digitized by Google

bed, at half ebb or flood, some of which was taken up for preservation, at a very low spring tide, on the 24th October, 1835, when the engineers were engaged laying down marks at the outer ends of the Oxcraigs for the foundation of the north wharf-walls of the first design of a pier at Granton, in seven feet water, clean blue clay ground.

If it is admitted, from hydrostatic facts, that the pressure of a body of water temporarily confined during the flood and ebb tides within so large an area, and twice in twenty-four hours attaining depths from eleven to twenty-six feet six inches or more, as the tides during the equinoxes, within the Forth, fall and rise on an average of three feet above or below the usual calculations of the tide tables,—such a powerful mass of water acting at the bottom with a force equal, if not superior, to the tidal current on the north shore, through 130, or more if necessary, rectangular arches, always covered by the tidal water in the harbour, which cannot disturb the vessels by any agitation, "because it becomes the breakwater, and far more secure and sheltered, with less risk of breaking adrift, like a floating one, which can only be secured by cables, moorings, and chains," the current outside and within is better directed in acting with great force on the bed of the harbour, as the winds and the tides direct, for effectually sluicing and clearing away all silt or deposit from within the proposed harbour and Granton Pier; and will soon prove practically the power and principles of this method of keeping harbours in tide or shallow water serviceable at all times and seasons, for the benefit and encouragement of the commercial interests of this great empire.

According to the authority of the Chevalier Du-Buat and others, "A velocity at the bottom, of thirty-six inches per second, will sweep along angular substances of the size of an egg." The areas of the arches in the Breakwater Piers are more than double this power for sweeping away such heavy substances, should they exist in any marine deposit, which cannot be at rest while all the ships floating in a harbour, or at a quay or wharf, create a current under their bottoms, which set in motion the particles collected round and about them. And it is clear, if once set agoing, they will find their way out; and the agency which brings them in is surely equal, with increased powers, to force them back again into the stream of the ocean, by the artificial means proposed for a clean and deep tidal harbour.

The model and cross sections of the proposed Breakwater Piers (with the exception of the arches) are taken from Mr. William Chapman's plan and specification for the eastern pier of Leith, which has proved a most substantial work in all its details, having withstood the storms and heavy seas breaking over it for sixteen years, with trifling repairs. It is a work for a pattern to all others in similar

Digitized by Google

situations—the combination of timber, stone, and other materials, to ensure solidity, strength, and durability, is entirely his own, and creditable to his memory and talents as an engineer.

In the same report and estimate, 1824, the whole expense of the proposed works at the entrance of Leith Harbour, including £30,343 for 3550 feet length of the eastern pier into ten feet low water, was £41,587 19*s.* 6*d.* Two contracts have been executed since, at prices per lineal yard of £52 12*s.* and £42, for 2500 feet, which has cost the trade of the port £41,996 19*s.* 6*d.*; yet the pier and harbour is still within the ancient bar, as represented in Greenville Collin's Chart of the Frith, 1686.

From the foregoing facts, an estimate can be formed of the probable cost per lineal yard, in deeper water, at low tides, for the north and east piers and quay walls, exclusive of the expense of opening up the channel between the Oxcraig Rocks, and clearing away, by a galvanic battery, a part of them on the east side of Granton Pier. The length of the above works is 6650 feet, or 2216⅔ lineal yards, and will, covering incidental expenses, amount to £48 10*s.* a yard, being less per yard for the first contract, and £4 10*s.* above the second, for Leith Pier.

It is with a deep feeling of the importance of the plan and model now submitted to parties who may be interested in the prosperity of the trade and intercourse connected with Scotland, by the establishment of a good harbour in the Frith of Forth; and the period has arrived when commercial enterprise and capital will contribute for this accommodation, or forego advantages tending to the increasing wealth and importance of the city of Edinburgh. Not less to the Glasgow and Edinburgh, North British, Edinburgh, Leith, and Granton, and other railway companies, starting up into active movements, and the noble and honourable proprietors of the splendid low-water piers of Granton and Burntisland, all are interested in fairly investigating this proposal, as it may lead others more capable to improve upon the suggestions of one who has had practical and professional experience of its importance as concerns the maritime prosperity of this country; and by the artificial method recommended, of increasing the velocity of the tidal waters on the south shore, where pointed out, the object will be obtained.

NOTE.

In a working model, on a reduced scale, is shown the action of the tidal waters in effecting a removal of any silt or deposit within the harbour and piers, by increasing the velocity of the currents approaching and passing through the arches, the entrance, and Oxcraig channel under the Granton Pier.

Digitized by Google

A caisson floats in a reservoir representing 293,333 superficial yards of the waters of the Forth, adjoining the proposed harbour, in fourteen feet low water, on the north and east sides, and always acting on the rectangular and parallel form of the works to the tides, whose pressure through the arches inwards or outwards, on ebb or flood, prevents all possibility of still water. If the flood current is required, the caisson is ballasted, her form displacing the water till it is neap tide on the shore, to eleven feet water, then to high-water-mark spring tides to sixteen feet six inches, and on the return of the ebb to low water repasses into the reservoir, by taking the ballast out of the caisson. The opening of each arch is five feet horizontal by six feet perpendicular, and fifty feet from its opposite opening through the foundation courses of the breakwater piers, where the tidal current in depth inside, as above stated, passes through them with powerful velocity, sufficient to prevent any deposit from taking place within the whole area of the harbour.

The diagrams represent twenty lineal yards of the inside elevation and profile of the breakwater piers complete, illustrating the position of the arches, with the details of the construction to that extent; so that the engineer, as recommended by the promoters of floating breakwaters, may adopt this principle to any tidal port, harbour, bay, or situation on the coasts of the United Kingdom[a].

[a] This paper has reference to the estuary of the Frith of Forth alone. The principle of constructing arches in breakwaters and piers is applicable to all harbours and landing-places for steamers or other trade, either new or under alterations or improvement, subject to the influence of tidal currents and eddies, in the vicinity of sand banks or shallow water, less than five fathoms, or fourteen feet at neap and sixteen feet six inches at spring tides.—B.

Digitized by Google

IRON ROOF

OF THE

NEW HOUSES OF PARLIAMENT.

THE erection of the New Houses of Parliament is an era in the history of British architecture, unexampled in the beauty of its effect and the solidity of its construction. There exists not in Europe an edifice so gorgeous or so nationally appropriate. The master mind of its architect has achieved in art what has been hitherto unknown in our national buildings[a] in this particular style, so congenial to Englishmen[b]. We venture upon this opinion, although in its present state it may, by some, be considered premature; nevertheless, the work of the architect is so far advanced as to determine its character in design and stability of construction.

Upon a very recent visit, we were struck with, and able to verify, the very accurate and well written article in the "Times" of the 10th of last month, which we cannot do better than at once copy from that journal.

"Since the last notice of this important work which appeared in this journal, very considerable progress has been made in every department, and the whole structure now presents that tangible and substantial appearance which enables the visitor to form a tolerably adequate idea of its magnitude, and of the accommodation it is calculated to afford. In order more distinctly to describe the present state of the

[a] We except Windsor Castle, as the *tout ensemble* is truly worthy of a sovereign's residence.

[b] We have the arms and badges of a long succession of our kings; images of ecclesiastical, military, and royal personages; appropriate legends in beautiful text run on every scroll: each emblem is characteristic of our country. The internal decoration is to be of a purely national character,—the absurdities of mythology utterly rejected,—and, if the architect's design for the great tower be carried out, we shall have a monument of English art which has not been surpassed even in antiquity. This building is the morning star of the great revival of national architecture. and art: it is a complete and practical refutation of those men who venture to assert that pointed architecture is not suitable for public edifices; for the plan embodies every possible convenience of access, light, and distribution of the various halls and chambers, without the aid of false doors, blank windows, mock pediments, adapted temple fronts, and show domes, to make up an elevation.—*Pugin on the Revival of Christian Architecture.*

Digitized by Google

works, it should be premised that the general design of the whole construction embraces the following main features. 1st, The river front, consisting principally of apartments to be devoted to the use of committees, meetings for conference, &c. 2nd, A parallel and corresponding front, facing the west and fronting the Abbey. 3rd, The clock-tower, situate at the north end of the building, to be appropriated to the residence of the Speaker. 4th, The Victoria tower, at the other or south end of the building. 5th, The central tower designed for the purposes of ventilation. And lastly, the quadrangular space inclosed by the exterior structure just described, containing the Houses of Lords and Commons. The works already executed, and now in progress, have been divided into five contracts. The 1st, the formation of the cofferdam and of the artificial embankment, extending along the river front. 2nd, The foundation of the river front of the building; both of which were let by tender to the Messrs. Lee, and have been long since completed. 3rd, The erection of the river front. 4th, The foundations of the Houses of Lords and Commons and other buildings in the quadrangle. And, 5th, the erection of those buildings; all of which were let to Messrs. Grissell and Peto, by whom the 4th has been completed, whilst the 3rd and 5th are in active progress. The river front has been carried up to its full height, and the greater part of the roof is completed. The exterior of this portion of the building presents a rich display of graceful mouldings, tracery, carvings, and decorations, with innumerable shields and heraldic devices, which, whilst they strike astonishment to the beholder, must raise in his heart a high admiration for native genius, which from the solid rock of massive limestone could, with an iron chisel and a wooden mallet, produce forms so beautiful and so intricate."

We must here pause to do justice to the "native genius" in the person of Mr. Thomas, a native of the county of Gloucester[a], who has had the execution and direction of the whole of the sculpture. Competent judges in heraldry and archæology speak in the highest terms of Mr. Thomas's execution. The heraldry in the river front consists of the arms of the sovereigns from the Conqueror to Victoria, both in-

[a] There are some curious facts on record connected with the name of Thomas. The principal mason in the time of Edward the Third, and the principal sculptor and mason in the time of Victoria, (the old houses and the new houses,) are of the same name, as per extract from "Britton and Brayley's History of the Ancient Palace at Westminster," p. 150.

"4TH EDWARD III.—1330. May 27th.—To Master Thomas the mason, coming first to Westminster, and beginning there upon the new Chapel of St. Stephen, '*et intrasura super moldas operanti*,' for his wages for six days, by order of the Lord Treasurer and Council, 6*s*.

"June 3.—To Master Thomas of Canterbury, master mason, working *et tractanti super trasuram*, 6*s*.

"June 10.—To Master Thomas of Canterbury, mason, '*operanti intrasura, et moldas de novo reparanti*,' for his wages, 6*s*."

Digitized by Google

cluded, with the arms of Victoria on the six oriels, accompanied with crests, badges, sceptres, swords of state, ribbons with appropriate mottoes, &c., with the name of each sovereign, dates of the commencement and termination of each reign. On the returns of terrace and flank of end towers are the badges of each kingdom, underneath elaborate crowns, supported by angels, with their respective patron saints in canopied niches. On the fronts of these towers are the several crosses of each saint, entwined with their proper foliage, and the badges of each house from the conquest to the present time. On the returns of the main building, or the north and south fronts, are the Victoria, clock, and central towers, which have each been carried to the height of about 33 feet, and have yet to be built considerably higher. These towers are equally rich in decorations with the river front, and are now being proceeded with very rapidly. The western front, which is to correspond with the river front, has not yet been commenced. Within the quadrangle, the exterior walls of the House of Lords have been built to their full height, and the roofing is nearly completed, the whole being expected to be covered in in the course of a few weeks, whilst very little progress above the surface of the ground has yet been made with the Lower House.

"It is hardly necessary to mention that the whole of the stone employed for the exterior work belongs to the magnesian limestone formation. For the interior work several varieties of the native oolite were originally employed, more especially that from Painswick, in Glocestershire; these, however, have been now entirely superseded by a remarkable fine description of oolite imported into this country from Caen, in Normandy. This French stone has for centuries enjoyed a very high reputation for the fineness of its texture, the beauty and smoothness of its surface, and the ease with which, under the chisels and graving tools of the mason, it can be fashioned into the most intricate forms; it was the favourite stone of the priest-architects who reared most of the English ecclesiastical structures in the middle ages, and must have been extensively imported into this country at a time when our own stone quarries were little worked, and the mineral resources of England but imperfectly understood.

"The colour of the magnesian limestone formed one of its recommendations with the commission of geologists and architects by whom it was selected. When first quarried, and for some time afterwards, whilst it retains its native moisture, the colour is not unlike that of brown sugar; when dry, the shade becomes much improved, being that of a delicate cream, and such is the condition of many blocks now to be seen in the walls; those composing the earlier portions of the building, however, have already assumed the dull, dingy, sooty appearance which is common to all

Digitized by Google

the buildings of the metropolis, and which will ultimately even reduce to an uniform shade every variety of colouring that can be introduced into the external walls of her buildings.

"In examining a work of this vast magnitude, employing in its execution about 700 artificers, it is impossible not to be struck with the regularity and precision which prevail in every department, and with the numerous novel and ingenious devices had recourse to with the view of shortening the labour and perfecting the construction of the undertaking. Mr. Allan, the able foreman of the contractors, is entitled to much credit upon these points: the practical operations are for the most part confided to his care, and to him the constructive professions are indebted, amongst other matters, for great improvements in the system of scaffolding, for the introduction of zinc plates or moulds in lieu of the old wooden templets, and for improvements in the application of the travelling crane, a machine capable of far greater range, and therefore of more extensive utility, than the ordinary fixed swing crane. Besides these improvements of Mr. Allan, we notice the application of Dr. Spurgin's patent machine for hoisting bricks and mortar, thus dispensing with mortar-carriers, (a class so well-known by the designation of "hodmen,") the employment of iron girders and binders instead of wooden beams for all the principal floors, and of the patent galvanized iron instead of slates for covering the roofs.

"The extensive use of iron, and the consequent exclusion of wood from all the main portions of the building, afford a very satisfactory security against fire, and we may therefore rejoice in the extreme improbability of the recurrence of such a catastrophe as that which destroyed its predecessor.

"In concluding these brief remarks, we cannot refrain from paying a just and well-merited tribute to the genius of the able architect who designed this building, and under whose direction it is now rapidly advancing to conclusion. Not alone does the design as a whole command respect and admiration for its noble and lofty proportions, its vast magnitude and the scale of luxurious amplitude which everywhere distinguish it; but, looking further into the structure, examining it piece by piece, and feature by feature, we are everywhere struck by new instances of ingenuity, skill, and talent, which are everywhere multiplied around, even down to the most insignificant details of secondary decoration."

The roofs represented in the eight Plates which accompany this paper are now in course of erection, and are as equally interesting to the engineer as to the architect, evincing at once the practical talent and the good judgment exercised in their design by the architect of this great national work. Of the superiority of iron over wood

Digitized by Google

in the construction of roofs for buildings, the architects of the present day are becoming fully convinced, and the splendid example now set before them by Charles Barry, Esq., should at least induce all who have hitherto been indifferent to the advantages of this material in the essential qualifications of lightness, strength, durability, and safety in cases of fire, to examine the subject with all the attention it deserves, and the result may be looked for in the more rapid progress of the substitution of iron for wood in constructing the principals of roofs, especially when of large span. Not to the roofs only, but to flooring joists or girders, the metal material is happily adaptable also, wherever resistance to fire, and great strength, with small section, are primary objects in their construction. Of these valuable properties, the architect of this edifice has wisely and very fully availed himself, and he has, moreover, been, by this selection, enabled to offer facilities for carrying into complete effect the most complicated details of construction in flues, &c., required for the proposed system of ventilation for the extensive pile of building under his care.

But beyond the use of iron in forming the principals of his roofs, Mr. Barry has ventured to a further step, of which those unacquainted with the experience that he is cognizant of might not fully understand the wisdom, but which is thoroughly approved by all practical and scientific persons who have examined the subject minutely. We refer to the covering of the roofs with cast iron plates of a thin section, and galvanized by a process now admitted to present the best yet discovered means of protecting iron work exposed to the air and weather from their otherwise injurious effects.

Upon the many substantial advantages thus attained, we are induced to state briefly the impressions we have received from an attentive examination, we might say, most interesting study, of the roofs delineated and detailed in the eight accompanying plates. The cast iron plates being cast of sufficient size to span the distance between each adjoining pair of principals, dispense with the necessity for any kind of boarding whatever, thus saving not only a great expense, but also diminishing the chances of damage by fire, which would, by destroying this boarding, leave the slates without sufficient support, thus making the whole roof liable to be broken in by their derangement; or, in the case of lead covering, the fire from the boarding communicated to the lead, would speedily reduce it to a liquid state, and create the most disastrous or fatal consequences. Again, the cast iron plates allow the formation of ornamental rolls on the exterior, and parallel with the rafters, at the same time having vertical joints beneath these rolls, which, together with the horizontal joints, are so contrived as to be perfectly impervious to the admission of water. The

Digitized by Google

architect being thus enabled to communicate an architectural character to the very roof, which cannot fail to be highly esteemed when seen in connexion with the striking features of the masonry below, when the edifice is completed. And these rolls, it must be remembered, which in slate covering would be impracticable, and in lead liable to considerable distortion and injury, are, when formed in iron, and cast as parts of the plates themselves, not liable to injury by any ordinary means or circumstances, and will always retain their form, position, and imperviousness to wet and weather. To whatever purpose the spaces or rooms within the roofs may be applied, —and these spaces must, from the high pitch of the roofs, be very valuable for many purposes,—it is evident that uniformity of temperature will be highly desirable; and this will be attained, it is believed, to a much greater degree by an iron covering than by one of lead, slate, or any other material. The corners of each plate being firmly secured by screws and snugs to the rafters on which they lie, a greater degree of lateral strength and stiffness is attained than can be had with any other kind of covering: in fact, the whole roof, principals, and covering, become one piece of framework, well knit and secured together at all points by metal connexions, so that the longitudinal tie-rods, which are introduced at the intermediate points, are very much lighter than would otherwise have been advisable, and yet are abundantly sufficient for their purpose. Much greater facilities are likewise offered by this description of covering for the attachment of ornamental dormer windows, which the architect has introduced for the purpose of lighting the rooms within the roofs, and which could not in any other material have been so neatly, durably, or safely constructed and attached to the covering. In point of durability merely, if lead be allowed a comparison with iron thus prepared and adopted, the latter must be pronounced the better material. As to weight, little or no difference can be stated; and regarding their comparative expense, it is believed, allowing fairly for all circumstances, the preference must be awarded to iron. Slate, of course, cannot sustain a comparison of durability, has little advantage in lightness, and not much in point of expense. But the many valuable peculiarities belonging to iron for the purposes required, and at some of which peculiarities we have above glanced, should be held thoroughly decisive as to its employment in the erection of an edifice of which not only the architect in the present age, but the nation for many centuries, should be justified in feeling proud.

The eight accompanying Plates represent two differently constructed roofs, one of which, shown in every detail in Plates 1 to 5, spans the whole river-front portion of the building, consisting of a centre portion of higher altitude than the remaining

Digitized by Google

parts, the two curtains. These, again, will be flanked by the return buildings, or wings, the construction of the roofs of which is intended to be similar to the curtains, excepting that over the air-chamber, forming the smaller span, as seen on Plate 1. Plates 6 to 8 represent the detail of the roof which is now being erected over the House of Peers, that portion of the palace having been much advanced before the House of Commons and other offices with which it ranges. The roofs of these, however, are intended to be exactly similar to the Peers' roof. The plates, therefore, refer equally to all these major parts of the building.

The curtain roofs consist of two spans, one towards the river, of 28′ 3″, the other of 11′ 7½″ clear of the walls; this latter being over a corridor and air-chamber, subservient to the design for ventilating the building. The front building is spanned by main girders, which bear seven small binders, running longitudinally with the front. These were, we believe, originally intended to assist in supporting the roof, but it has been more judiciously made independent of them, and of adequate strength to support by itself any weight to which it can in practice be subjected. Excepting the shoes, which are cast, the whole of these principals, with the connecting bar, V, are of malleable iron; the several bars being simply cut at the ends (mostly square) to templates, and punched in the machine for the bolts that connect them with the shoes and with each other. The larger roof consists of two rafters, J J, three inches and a half by five-eighths of an inch thickness, being placed edgewise; a tie-bar, two inches by half an inch, marked K; a queen-tie, L, three inches by half an inch; a king-post, M, two inches by half an inch; two queen ditto, N, of the same dimensions, and four struts, marked O O O O, three inches by half an inch. The roof is strengthened likewise by two double suspending bars, P, reaching from the rafters to the tie-bar, and passing outside of the struts O, and of the queen-tie L; each of these suspending bars is two inches by half an inch. Two double struts, Q, each three inches by five-eighths of an inch, connect the lower ends of the suspending bars with the shoes D, in which the rafters are met by the queen-tie and queen-posts. These suspending bars and double struts are united with the several other members of the principal merely by small bolts passing through them, and without introducing any shoes whatever. The shoes, it will be seen, are of varying patterns, and are cast as light as possible. Indeed, were we disposed to take exception to any part or detail of this roof, it would be with regard to the shoes, which considering the brittle nature of their material—cast iron, and the great importance of guarding against their injury, seeing how wholly essential they are to the stability of the roof, we should have been disposed to make somewhat stronger than those now described. Those shown at figures 15 and 17, Plate 2, should have especially been strengthened

Digitized by Google

at their inner angles by small ribs, similar to that shown at fig. 24, where we have exhibited what would be an improvement, without adding in any material degree to the weight of the shoes.

Plate 2 represents the details of all the shoes and connected points of the large and small roofs over the north and south curtains.

Fig. 3 is the side view of part of the ridge piece, which is cast in lengths, and joined together in the manner shown, by casting two projecting cheeks, or jaws, on one end of each length, between which the bare end of the next length is placed, and connected by two screwed bolts with nuts passing through holes cast in them for that purpose. In this figure, also, a notch is shewn in the under edge of the ridge piece, into which the upper edge of the shoe A, fig. 6, is fixed. Fig. 4 is a plan, and fig. 5 a side view, showing the shoe A, as fitted to the ridge piece.

Fig. 6 is a front view of the upper, or king shoe, J J being the rafters, and M the king bar, or post. The dotted lines on each of the shoes show the extent to which each of the bars is admitted within the casting, and also the space allowed for fitting them, leaving as much as possible in each shoe of solid metal. It will be noticed in the side views of the several shoes, that every bolt-hole is strengthened by a boss, or ring, cast around it. It is also to be remarked, that in all cases (except the solitary one of that end of the bar V which is held within the shoe D, fig. 1, Plate 1) the bars are formed with square ends. By this plan, the trouble of cutting the ends of the bars is much less than if they had to be fitted to angular templates.

Figs. 8 and 9 are a side and front view of the shoe R, which forms the king shoe of the smaller or air-chamber roof, and also a connexion with the flat or slightly inclined rafter V.

Figs. 10 and 11 show side and front views of the small shoes E, connecting the rafters J, with the struts O.

Figs. 12 and 13 represent front view and plan of the middle shoe B, which serves to connect four bars, viz.: — the queen-tie L, the king-post M, and two struts O O. This shoe is also perforated with a central hole, to admit a longitudinal tie-rod.

Figs. 14 and 15 refer similarly to the shoe C, through which the rafter J passes entire, and which also receives the end of queen-tie L, and queen-post, N.

Figs. 16 and 17 show side and front views of D, the corresponding shoe to C, but in this an additional fork projects upwards, to receive the end of the flat rafter V. In these two shoes (C and D) holes are cast to admit longitudinal tie-rods.

Figs. 18 and 19 show the shoe F, connecting the rafter J with the strut O, and having a hole cast in for a longitudinal tie-rod.

Digitized by Google

Figs. 20, 21, and 22 show the lower shoe G, through which the tie-bar K passes entire, and which also receives the foot of the queen-post N and strut O. This shoe has also provision for longitudinal tie-rods.

Figs. 23 and 24 represent the bearing shoe H receiving the foot of rafter J and end of tie-bar K. This shoe bears upon the top of the binder, and the small shoulder or projection at *a* bears against the inner edge of the flange, and transmits the outward pressure produced by the weight on the roof to the binders.

Figs. 25 and 26 show the shoe S connecting the rafter T of small roof with the tie-bar U.

Fig. 27 shows the section of the cast iron wall plates, which bear continuously on the walls, and have suitable flanges cast on to receive the heels of rafters T, through which they are bolted. In the plan fig. 2, Plate 1, it is shown that the principals are fixed at 2′ 10⅞″ apart from centre to centre. The flat rafter V is supported near the middle of its length in flanges cast upon a continuous wall plate, which is bedded upon a middle wall, as shown in fig. 1, Plate 1.

Plate 3, figs. 28, 29, and 30 show side elevation, plan, and cross section of the middle wall plate last described. Figs. 31, 32, and 33 are similar views of the two side wall plates shown at W P, fig. 1, Plate 1. These plates are cast in lengths and joined by dovetailed tenons and mortices, as seen in figs. 29 and 32.

Figs. 34, 35, and 36 represent the cast iron gutters, the position of which within each of the walls will be understood from fig. 1, Plate 1. Fig. 34 is partly longitudinal elevation and partly section; fig. 35 is a plan, and fig. 36 a cross section. *a* is a cast iron flashing plate formed to rest within the back apron *e* of the gutter, and also having a shoulder in which rests the cast iron chequered open spaced grating *f*. This flashing plate *a*, rests immediately upon the rafter, and is fixed beneath the lower range of cast iron plates with which the roof is covered. Ample scope is thus ensured for the certain discharge of all the roof water into the gutter. The flashing plates are cast in lengths and jointed in sockets, as shown at *b b*, with countersunk headed and galvanized screws. The gratings *f* are hinged at *g*, to small bearers marked *i i*, which bearers are supported by screw bolts upon the small brackets *c c c*, cast upon the top edge of the gutter for that purpose. The gutter is jointed, as shown at *d d*, in socket-joints, each having two grooves and fillets, as shown in figs. 34 and 35, which fit respectively into each other, and by means of countersunk headed and galvanized screws, form a perfect water-tight joint. At all these joints, a mixture of red lead, putty, &c., is used to complete the surfaces and prevent the possible chance of any water *passing through* the joint, though it should trickle into the inner edge of the joint. The gratings *f* will, of course, prevent any

Digitized by Google

considerable matters getting into the bed of the gutter so as to interrupt the discharge of the water, which is conducted down by vertical pipes, some of which are fixed within central openings in the turrets, and others descend the walls in the manner of ordinary rain-water pipes.

We have now to describe the kind of cast iron plates which are used to cover in these roofs, and shown in detail in Plate 4. All these plates are similar in the vertical rolls by which the joints are covered; but in the longitudinal joints the plates used to cover the steep sides of the roofs differ from those adapted to the flat, (extending from D to R, figs. 1 and 2, Plate 1.) The plate used for the steep pitch is shown at fig. 41, which is an upper or outside plan; fig. 42, which is an edge view, showing the upper fillet, and by the dotted lines indicating the thickness of the plate. That part of the sectional figure 39, lying between figs. 41 and 42, shows a section through the joint of two plates. Fig. 38 is a plan of three ranges of plates for covering the flat, and partly broken out for the purpose of showing more distinctly the mode of joining adopted. The upper plate X is formed to receive the lower edge of the plate W, starting the steep back of the roof. The lower edge of X is formed with two parallel projecting fillets underneath. The plate Y has two similar fillets projecting on its upper surface, which fit into, behind, or above the lower ones described for plate X. This plate Y may be regarded as an ordinary flat covering plate; the lower range, marked Z, is peculiar in having its lower edge rounded over so as to entirely protect the joint below; the vertical rolls upon these plates are also cast so as to curl over the under plate. These plates have each two ears or lugs (marked *r*) cast on the under side, which clip over the rafter, and bolts pass through them and the rafter. The upper plates have short ears only (marked s s), which embrace the rafter and steady the plates. The plates are provided to be secured to the rafters by screws, one at each corner of the plate, and the small angles cut off, as at *m*, are to afford facility in driving the screws into the rafters.

The whole of the covering plates, gutters, flashing plates, gratings, and outside screws for connecting plates, &c., are subjected to the process of galvanizing.

Plate 5: figs. 43 and 44 exhibit the ornamental ridge of cast iron, which is intended to be fixed to the ridge piece, fig. 6, Plate 2, by straps (*t t t*) cast on the lower part of the apron (marked *p p p*), and bolted through the ridge piece. Fig. 44 shows the transverse view of the crown, standard and buttresses, which will occur at every distance of 17′ 5¼″, being opposite to the buttresses of the front of the building.

Fig. 45 is the front elevation; fig. 46 the side elevation; and fig. 47 the section of large cast iron dormer windows, introduced along the river-front of the

Digitized by Google

roof, to give light to the roof. Figs. 48 and 49 show another smaller dormer, which will be fixed above the other, and in the same vertical line with it, for a similar purpose. The mode of forming and fixing these parts will be apparent from the plates, aided by a little description. The dotted lines B B and C C, show the lines on which the sections are taken. Each of the dormers is in one casting; the open spaces in front and at the sides having rebates formed for receiving the glass. The plates on which they are fixed are formed with openings corresponding with the space required for the dormers, and are cast with rims of about two inches wide around these openings. To these the lower edges of the dormers are fitted, the dormers resting outside the rims, and being secured by screws having countersunk heads on the outside. The lower dormers occupy the depth of two covering plates, and are fitted to close over the joint of the plates. By these rims, all water is of course prevented from entering.

Dormers of a similar kind to the larger one here shown, are introduced upon the flat joining the large and smaller roofs; the details of these exactly resemble those just described, with such alteration as is required to fit them to the different angle at which they are bedded.

The longitudinal tie-rods, which pass through the shoes as already mentioned, are formed in lengths, and joined by cast iron cylindrical sockets, having two key-ways cast in and through them. The ends of the rods are formed with corresponding slots, and the two ends of the rods being placed in the socket, keys are driven in through the socket and the two rods, thus connecting them securely.

The weight of the several parts of this roof is as follows:—

Each principal complete, comprising the large and the smaller roof, (excepting the cast iron shoes, the bolts, and the double suspending bars P, and struts Q, before mentioned,) weighs 8 cwt. 2 qrs. 4 lbs.

Each set of shoes, complete, weighs 2 cwt. 18 lbs.

The wall plates, 2 cwt. 15 lbs. each.

The wall plates for flat roof, 1 cwt. 2 qrs. 14 lbs. each.

The gutters, 7 cwt. 8 lbs. each length.

The covering plates, about 1 cwt. 14 lbs. each.

The flashing plates, about 1 cwt. 1 qr. 15 lbs. each.

The large dormers, 2 cwt. 2 qrs. 4 lbs. each.

The small dormers, 2 qrs. 12 lbs. each.

The whole of the iron exposed to the weather is galvanized by Messrs. Malins and Co. The heads of screws, &c., wherever they are exposed, are likewise protected by this process; the screws being also completely coated in the same manner. The principals of the roof, although not exposed, but in contact with the under side of the

Digitized by Google

covering plates (which are coated with the preservation metal on both sides), are painted with several coats of a metallic paint, which is said to be eminently efficacious in preventing the process of oxydation taking place, or being transmitted from the iron with which it is covered.

Plates 6, 7, and 8 represent the roof now erected over the House of Peers, and which is to be extended, of exactly similar construction, over the House of Commons and adjacent apartments. The span of this roof is forty-five feet two inches.

Plate 6, figs. 1 and 2, show the elevation and plan of the principals.

Plates 7 and 8 comprise all the details of shoes, &c. The same letters are used to indicate the same parts in these three Plates, and we therefore need not, in the description, specify the particular Plate referred to in each case. The main rafters N N, and the common rafters V V, with the top flat rafter Q, and top common rafter W, are of rolled T iron, the sections of which are shewn in fig. 10. The main tie-beam O, the upper tie-beam P, the bars R, S, T, and U are all of flat bar iron. The struts Y, X, Z, and Z^1, are of cast iron, of cross section. The wall plates W P, purlins P^1 P^2 P^3 P^4 P^5 P^6, bearers B^1, B^2, B^3, and lower bearers L B^1, L B^2, L B^3, L B^4, are all of cast iron. So also are the shoes, lettered from A to M consecutively. The tie-beams O and P, and bars R, are each in one length from end to end. The bars R are double. The principals are seven feet six inches apart from centre to centre, with two common rafters between each, resting in sockets formed on the purlins P^1, &c. The covering plates will be secured upon these common rafters, the plates being thus two feet six inches in width from centre to centre of the rolls, which cover the vertical joints. The lower beams L B^1, &c., are cast with shoes projecting from their lower flanges; these shoes will receive the timbers from which the ceiling of the house will be suspended.

The shoes A bed upon the walls, and have caulking pieces cast underneath. They receive the main tie-beam, secured by their screwed bolts and nuts; they also receive the heels of principal and common rafters, secured by bolts, and have projecting shoes cast on either side, for receiving the lower beams L B^1, and the wall plates W P, each fixed by bolts and nuts. The wall is built up underneath the wall plates, to form a solid bearing for them throughout their entire length.

The shoes B receive the main tie-bar that passes through them, the bars T and the cast iron struts Z. Two bolts secure the tie-beam, and two more secure T and Z.

Fig. 3 is a front view; fig. 4 a side view; and fig. 5 a plan of the shoes A; from which their construction will be perfectly understood.

Figs. 13 and 14 are front and side views of the shoes B, shewing the sockets for lower beams L B^2.

Digitized by Google

The shoes C receive the tie-bar through them, and the ends of the two struts X and X^1. The bars R R also pass through these shoes, and are secured by a bolt in the upper part of the shoe, and a key through the bars below the shoes. Figs. 6 and 7 are side and front views; and fig. 8, a sectional plan of these shoes; shewing also the sockets cast on them to receive the lower beams L B^3.

The shoe D is shewn at fig. 11. The tie-beam O passes through it. The bar S is received in a socket and attached by a bolt, and sockets are also cast on it for the lower beams L B^4.

Through the shoes E, F, E, the main rafter passes; they are also formed to receive the ends of the purlins. The purlin P^2 constitutes likewise a beam ranging with those marked B^1, &c.

The upper tie-beam P, and the double bars R, pass through the shoes G, which also receive the ends of the cast iron struts Y and Z^1. The bars R are also keyed together close below these shoes.

The shoes H receive the upper tie-bar and the bars U. These bars are double, and pass through mortices formed in the cast iron struts Y, and are bolted through eyes formed in the bars and in the strut.

The centre shoe I receives the tie-bar, which passes through it, the bar S, and the two struts X X. It also has sockets for the cast iron bearers B^3. Fig. 29 is a front view of this shoe.

Figs. 20 and 21 show the shoe K which is formed to receive the main and common rafters N Q and V W; the double bars R R, keyed above it; and the purlins P^4.

The shoe L is shewn at fig. 22. The rafter Q passes through it, and the purlins P^5, which rest between and are bolted through sockets formed upon the upper part of the shoe, are cast with sockets to receive the common flat rafter W.

The shoe M, fig. 23, has the flat rafter Q passing through it, and supports the upper ends of the cast iron struts Y Y. The upper part is formed to receive the purlin P^6, which is cast with ears to support the common rafter W.

Fig. 15 is a section of the purlin P^4. Fig. 16, a section of the purlin and bearer P^2. Fig. 17, a section of the purlins P^1 and P^3. Fig. 18, a section of the purlin P^5; and fig. 19, a section of the bearers B^1, B^2, and B^3. These five figures are to the scale of three inches per foot.

Besides the beams B^1, &c., the lower beams, L B^1, &c., and the purlins P^1, &c., the longitudinal connexion of the principals is further secured by diagonal cast iron struts or braces, shewn at *b*, fig. 6, and at *a*, *b*, fig. 27. These do not cross each other, but incline alternately in opposite directions, there being one of them between

Digitized by Google

each two contiguous principals. They are in the shape of a cross section, and are secured by bolts in sockets formed in the under surface of beams B^1, and on the upper surface of the lower beams L B^3.

The details of covering plates, dormers, &c., are very similar to those described in detail for the curtain roofs; the gutters being of course much larger, to provide for the great surface of this roof.

The whole of the work is deserving of commendation for the workman-like and correct manner in which it is executed, and reflects much credit upon Messrs. Bramah and Cochrane, who have had the execution under their care. That for the river-front portion of the building was prepared at their works at Woodside, near Dudley; and the roof over the House of Peers, &c., at the Horseley Iron Works, another of their establishments.

J. W

Digitized by Google

FIG. 1

ELEVATION

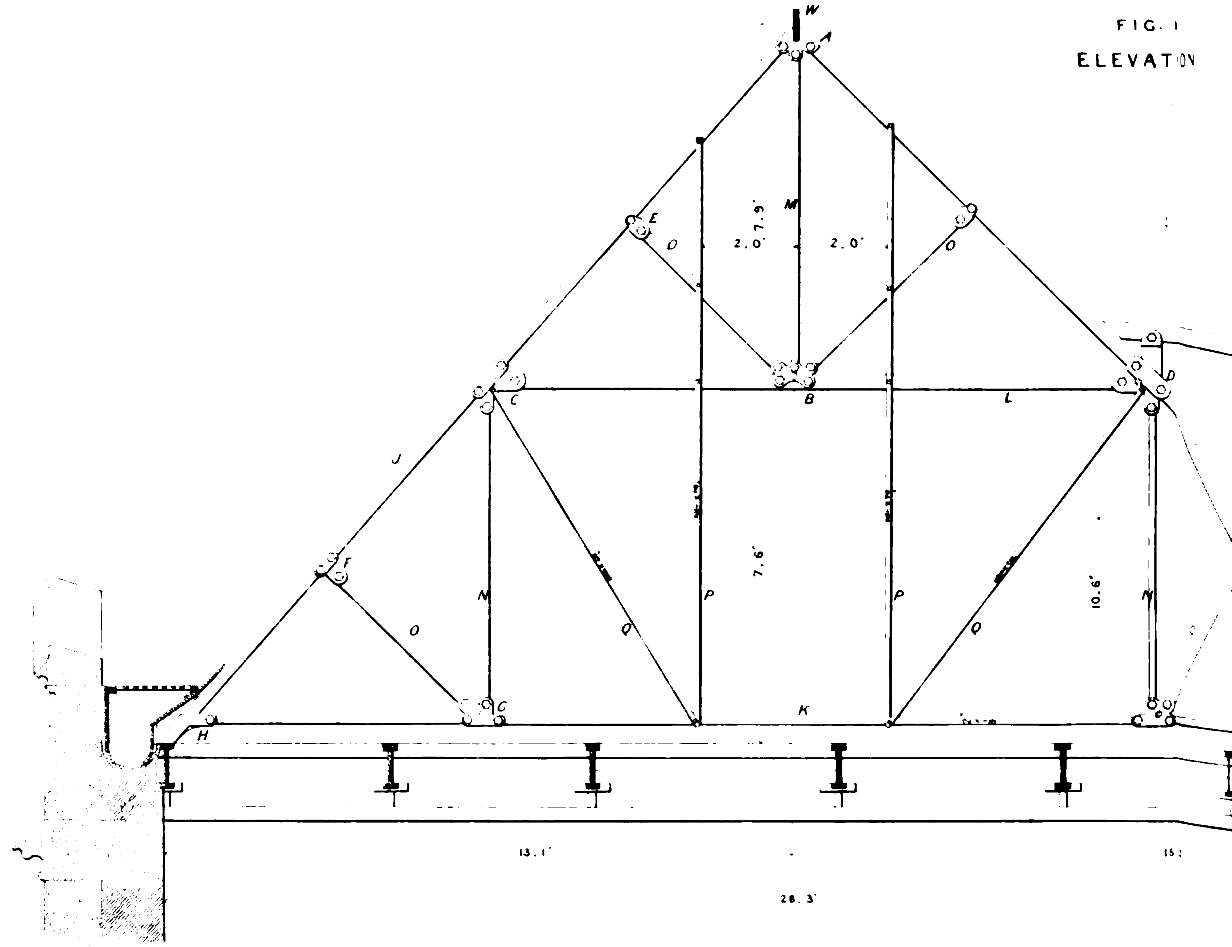
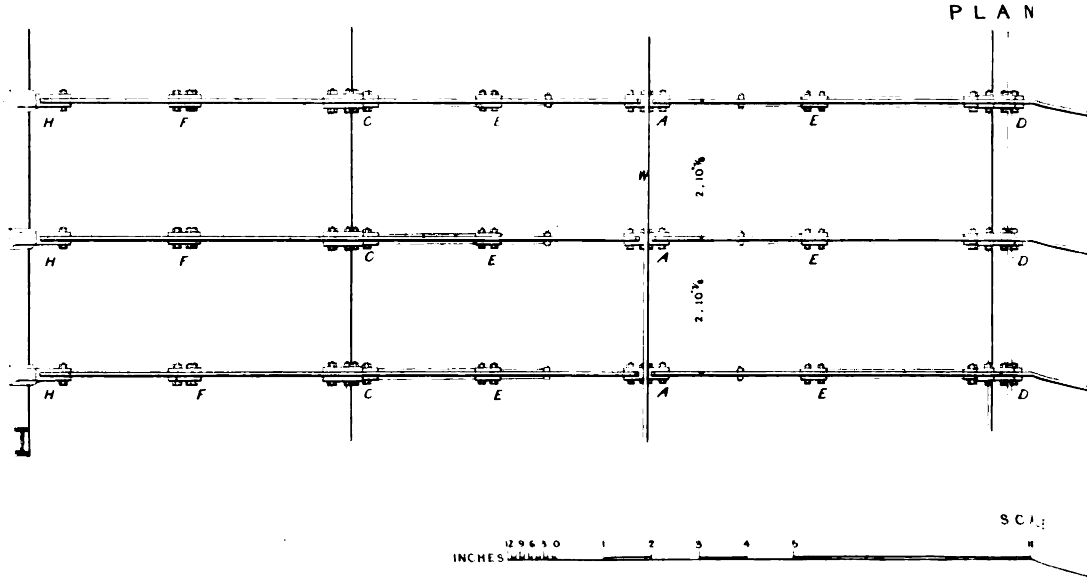


FIG. 2

PLAN



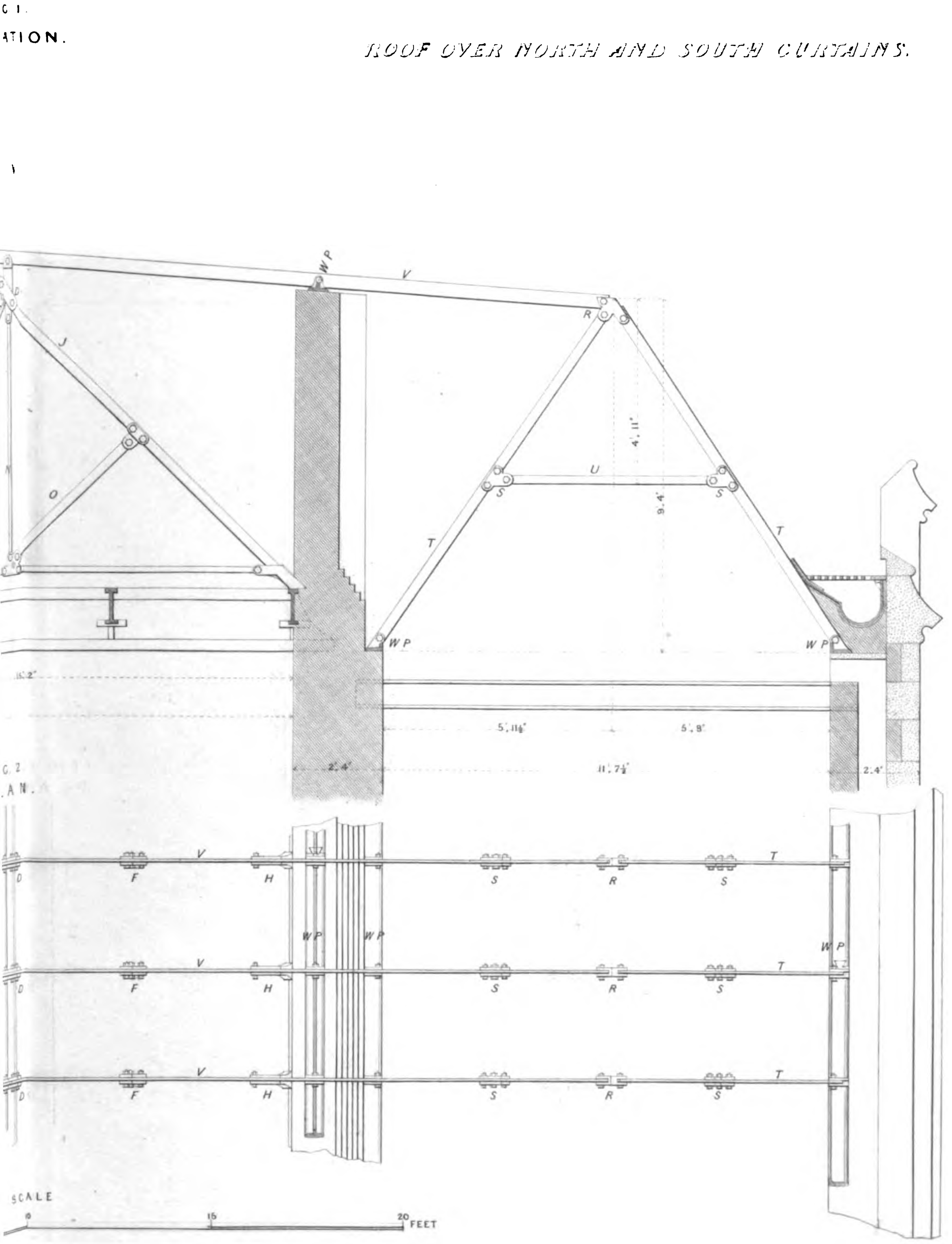
London Published by John

Digitized by Google

Plate I.

NEW HOUSES OF PARLIAMENT.

ROOF OVER NORTH AND SOUTH CURTAINS.



J. Weale 59 High Holborn 1844

Digitized by Google

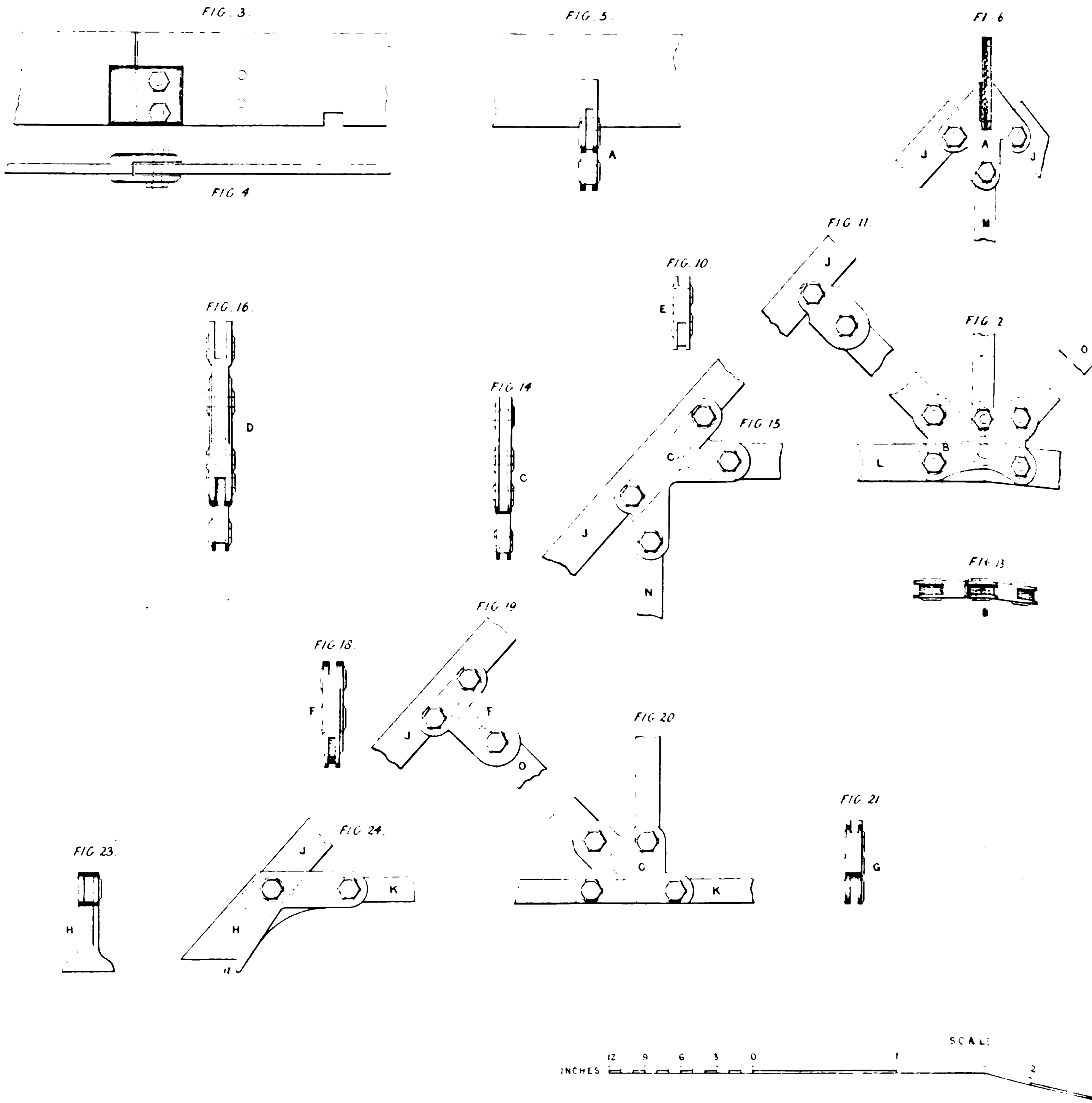
Digitized by Google

Digitized by Google

NEW HOUSES OF PAR

ROOF OVER NORTH AND SOU

DETAILS



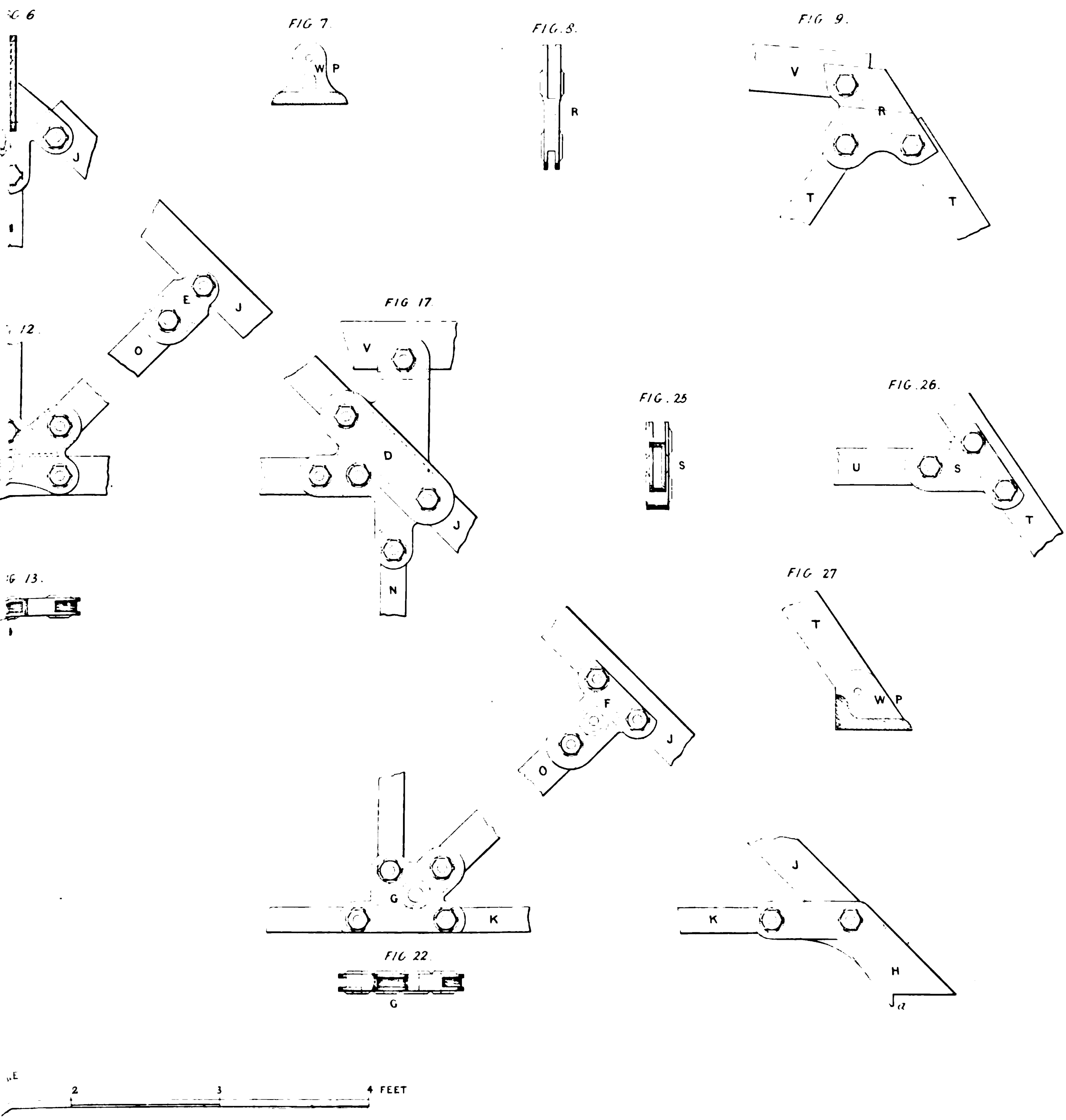
London Published by John

Digitized by Google

:F PARLIAMENT.

AND SOUTH CURTAINS.

LTTS.



R.K. ... Lap

...Weale 59 High Holborn 1841

Digitized by Google

Digitized by Google

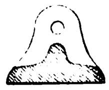
Digitized by Google

NEW HOUSES O

ROOF OVER NORTH A

DETAI

FIG. 30.



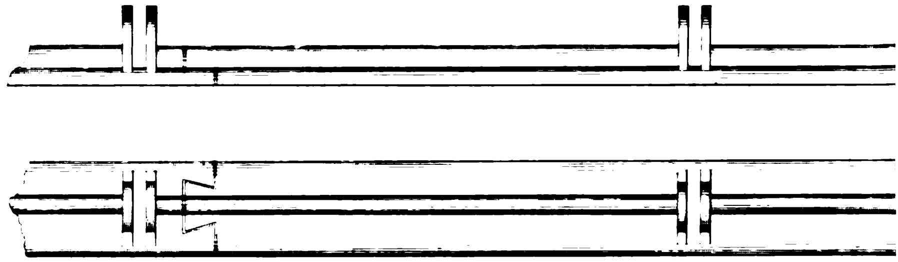
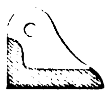


FIG. 33.



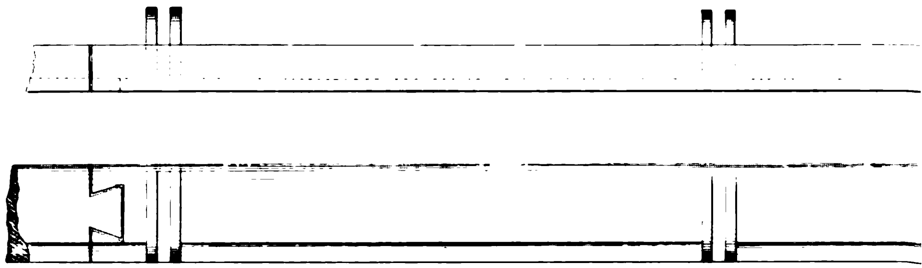
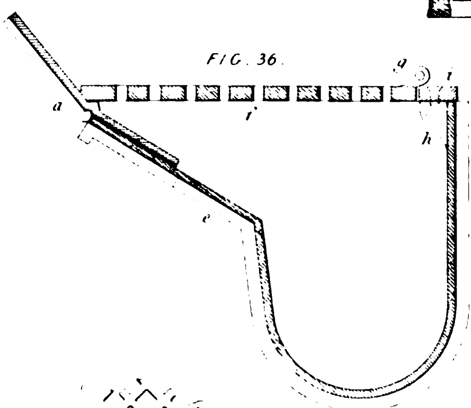


FIG. 36.



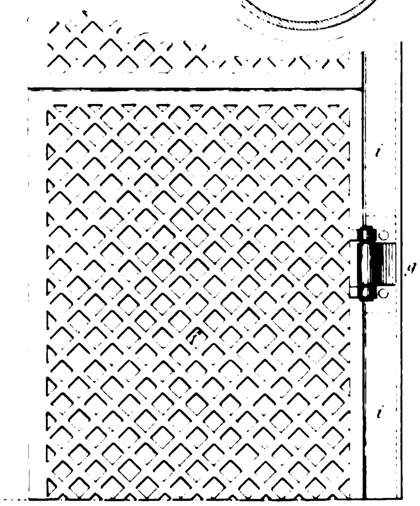
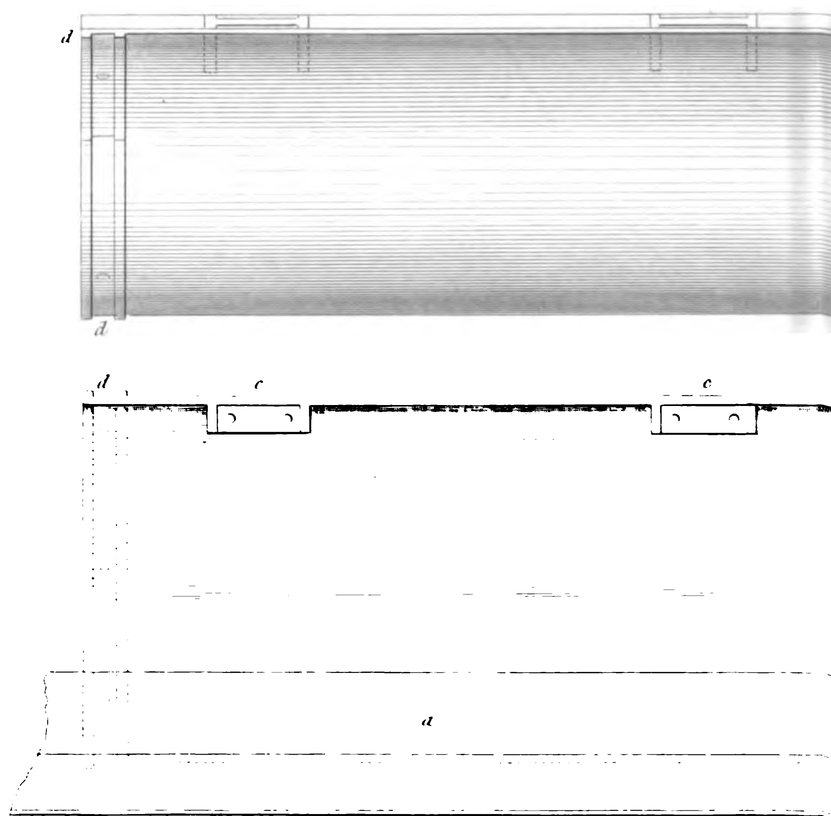
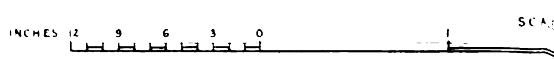


FIG. 37.





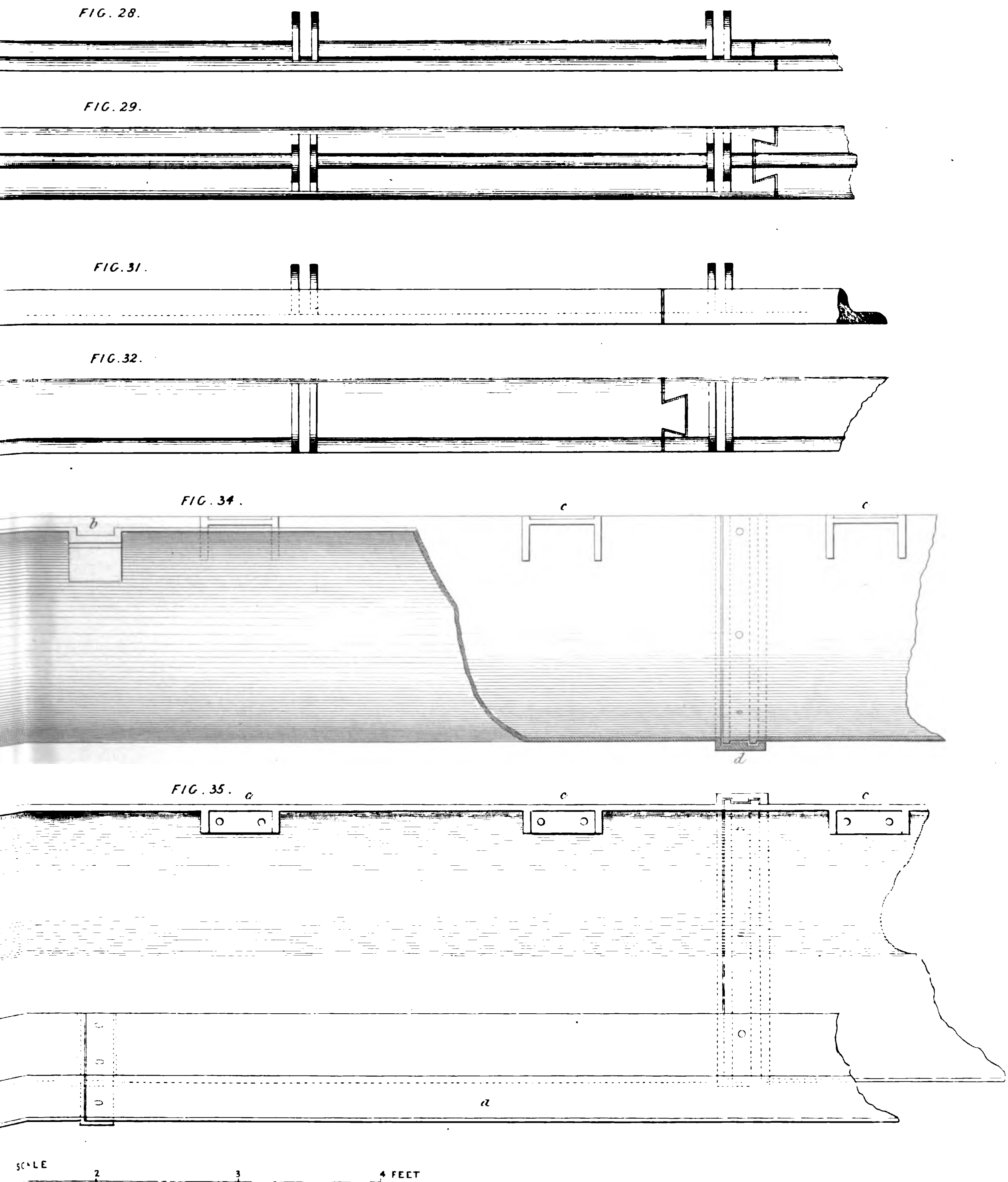
London Published by

Digitized by Google

OF PARLIAMENT.

AND SOUTH CURTAINS.

ALLS.



B. R. Davies Sculp.

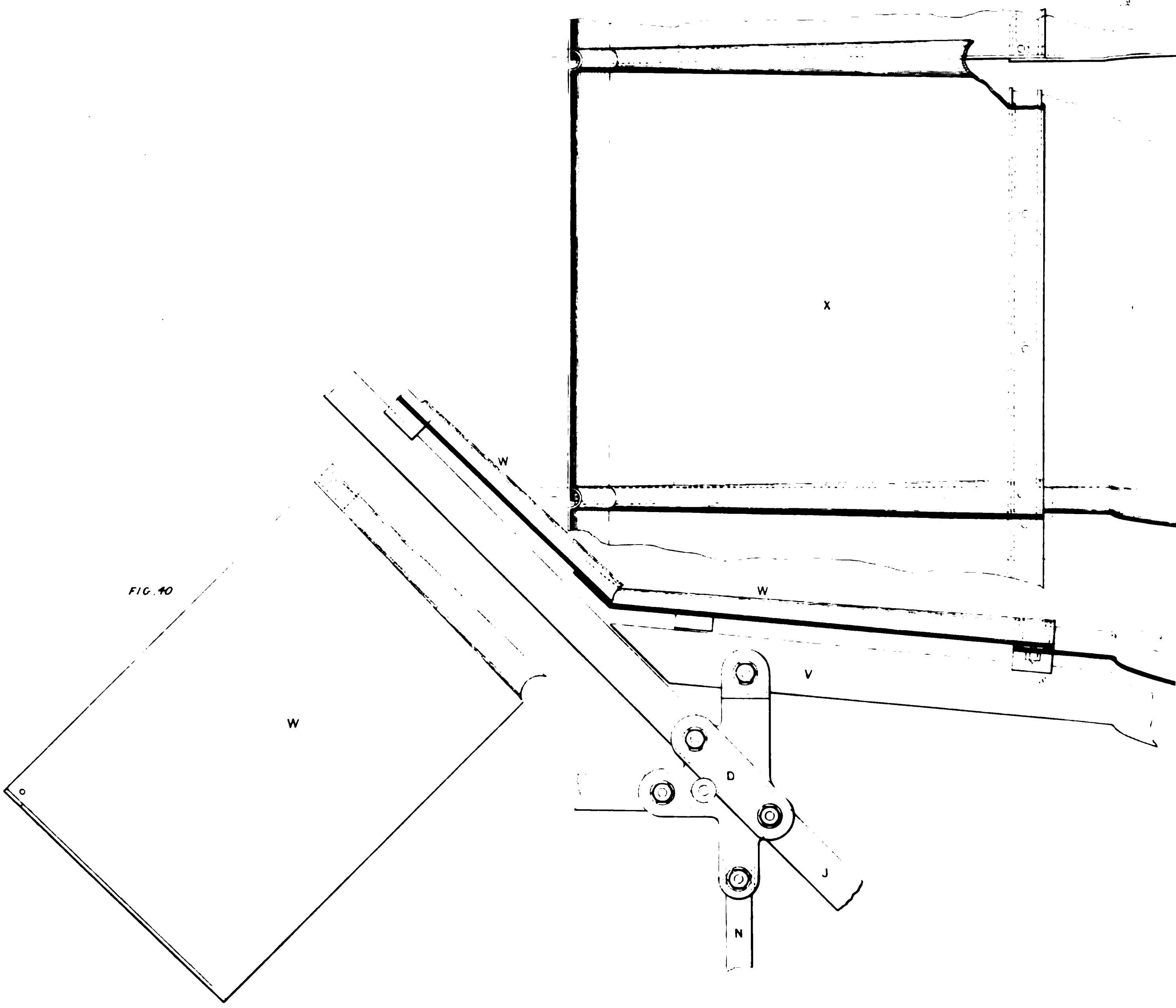
John Weale, 59 High Holborn 1841.

Digitized by Google

Digitized by Google

Digitized by Google

FIG. 40



NEW HOUSES OF PARLIAMENT.

ROOF OVER NORTH AND SOUTH CURTAINS

DETAILS OF COVERING PLATES

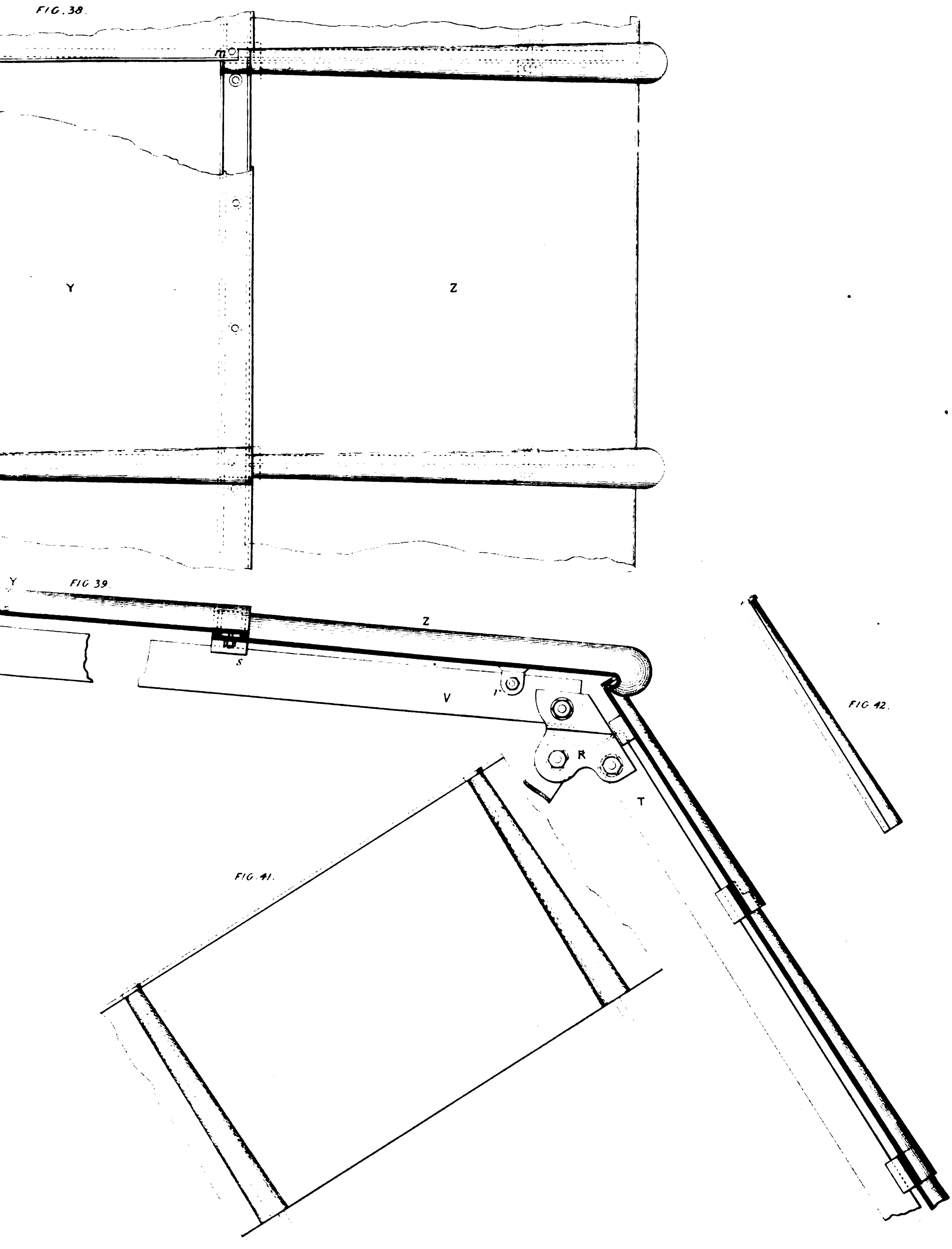
SCALE

INCHES 12 9 6 3 0 1 2 3 4 FEET

London Published by John

Digitized by Google

Plate 4.



B. R. Davies sculp.

... & 59 High Holborn 1841.

Digitized by Google

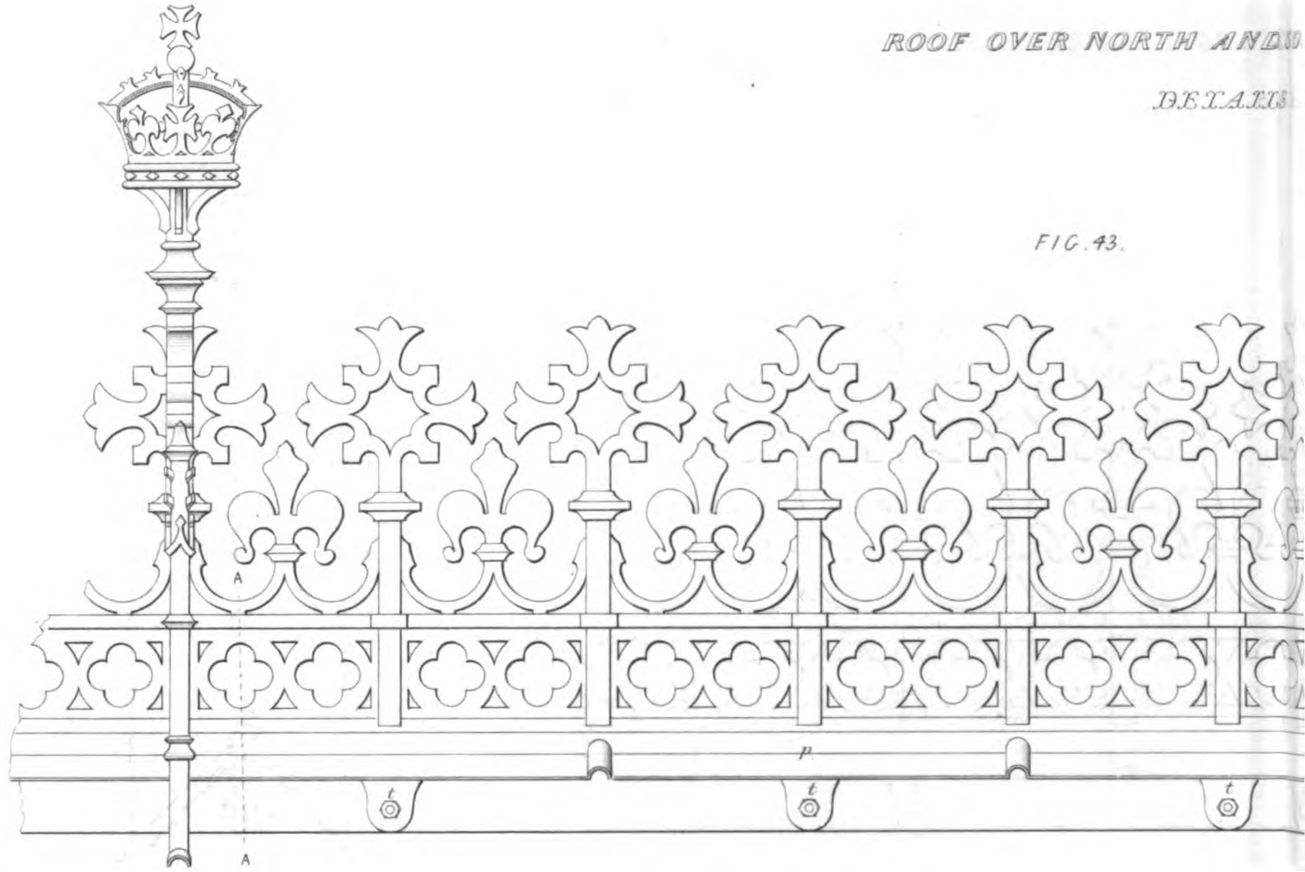
Digitized by Google

NEW HOUSES OF

ROOF OVER NORTH AND

DETAILS

FIG. 43.



INCHES 12 9 6 3 0 1

FIG. 46.

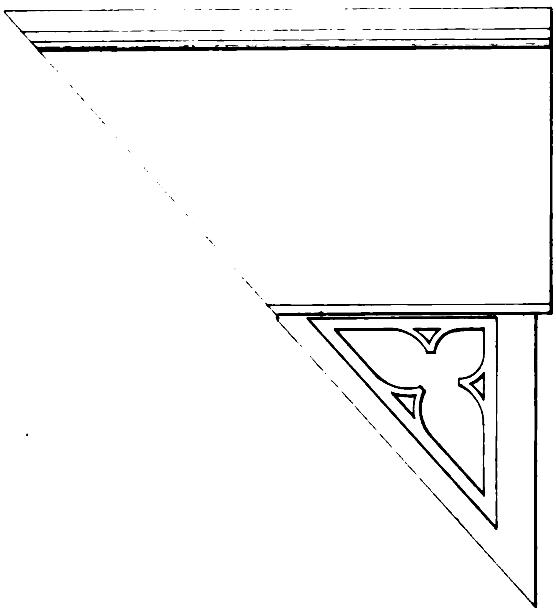
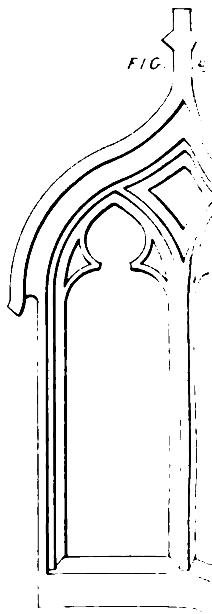


FIG.



INCHES 12 9 6 3 0 1

London. Published by John

Digitized by Google

F PARLIAMENT.

D SOUTH CURTAINS

ILS

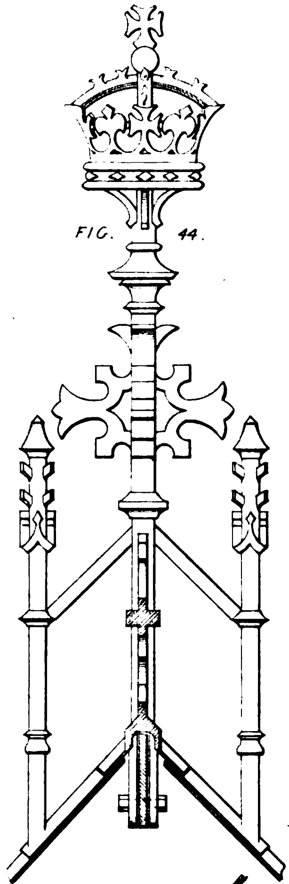
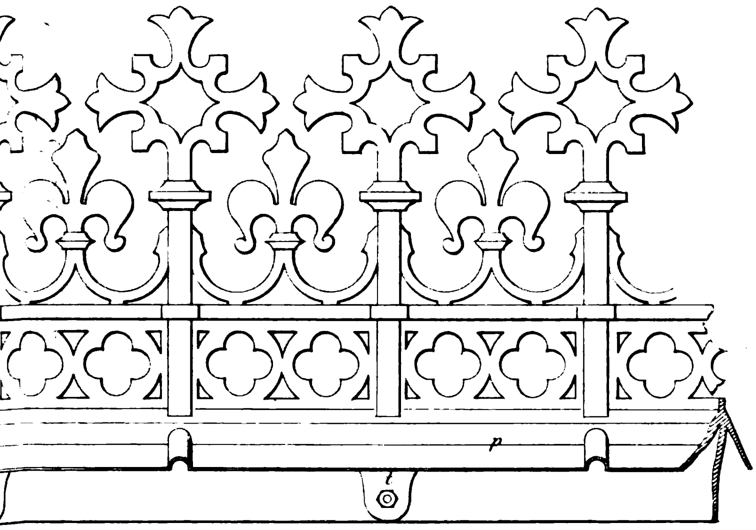


FIG. 44.



SCALE 2 3 4 5 FEET

45.

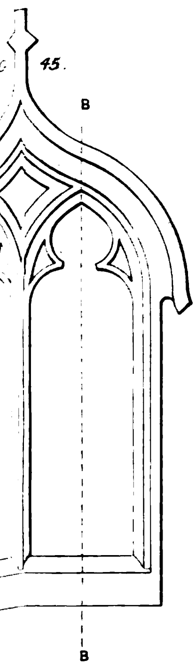


FIG. 47.

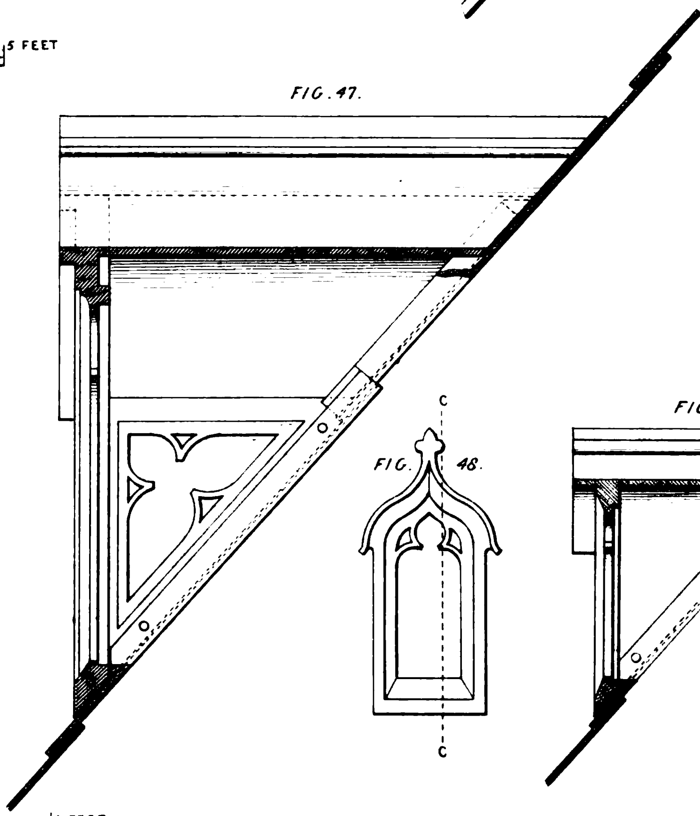
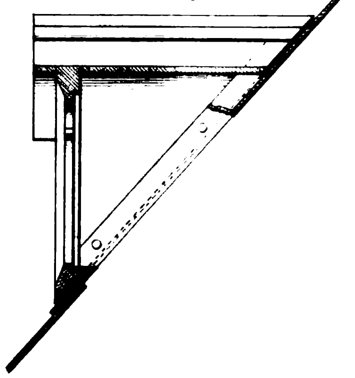


FIG. 48.

FIG. 49.



SCALE 2 3 4 FEET

B.R. Davies Sculp.
16 George Street Euston Sq.

Weale, 59 High Holborn, 1844.

Digitized by Google

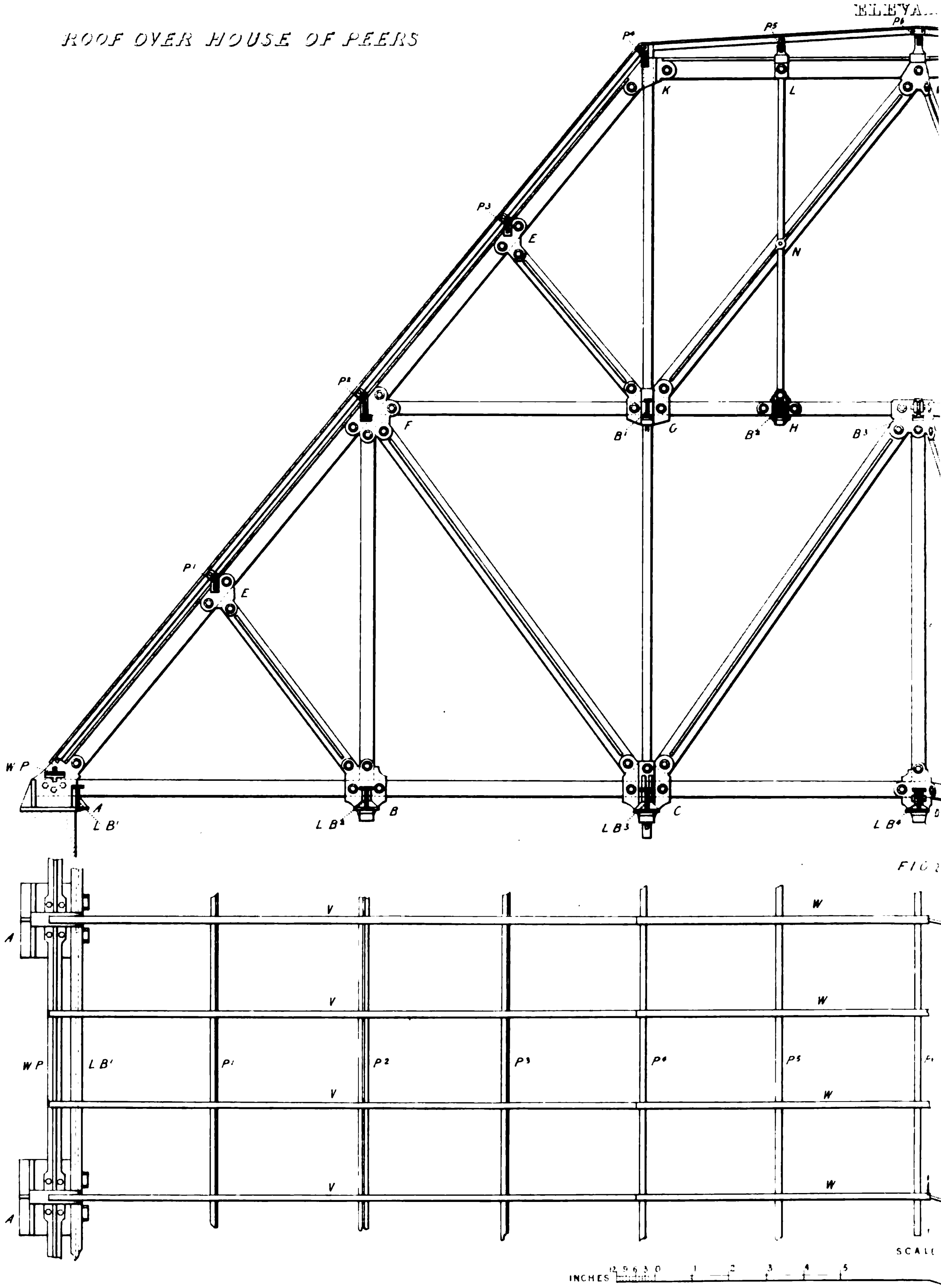
Digitized by Google

NEW HOUSES OF PARLIAMENT.

ROOF OVER HOUSE OF PEERS

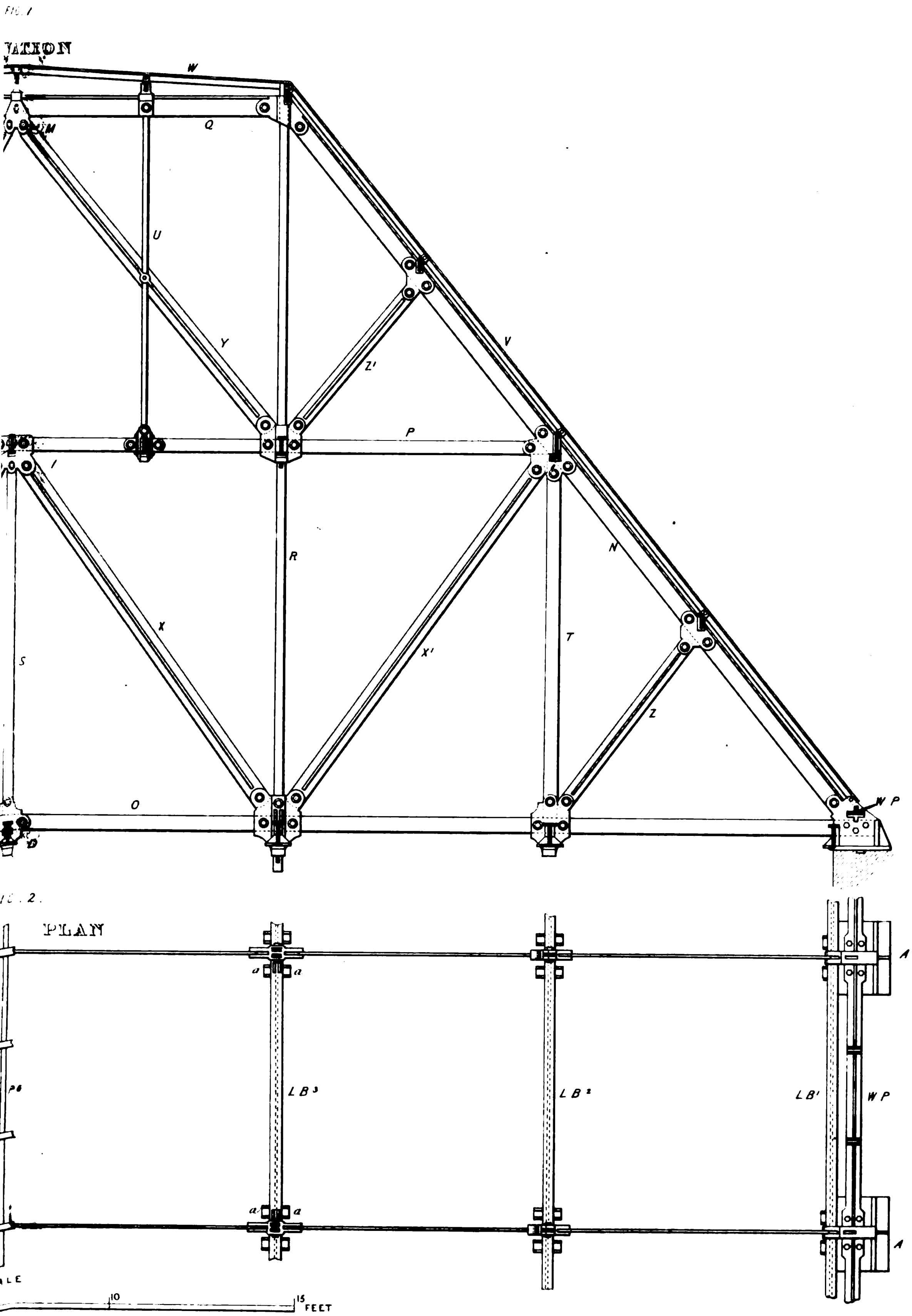
FIG

ELEVA...



London Published by John W...

Digitized by Google



Keele, 59 High Holborn 1841

B.K.Davies

Digitized by Google

Digitized by Google

Digitized by Google

NEW HOUSES OF

ROOF OVER HO

DETAI

FIG 3

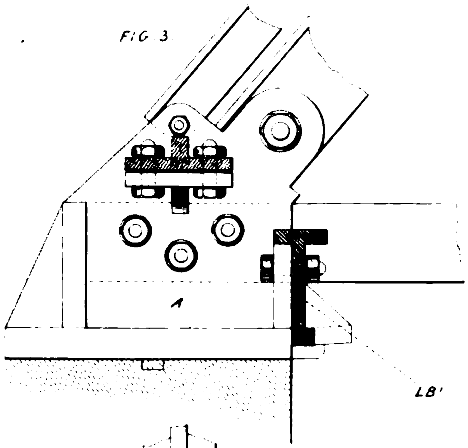


FIG 4.

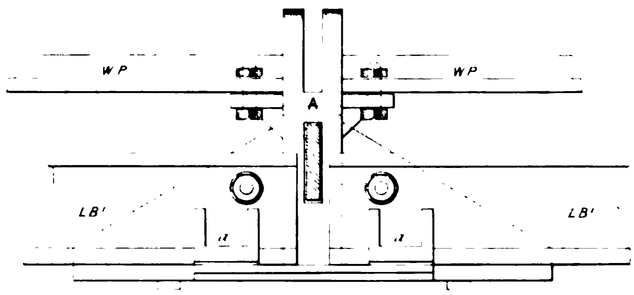


FIG 5

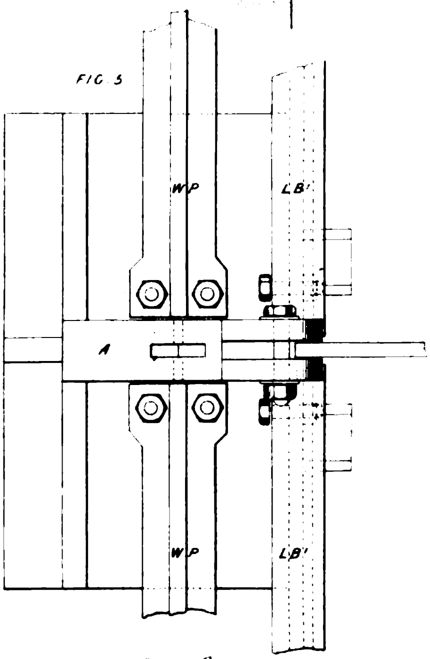


FIG 9.

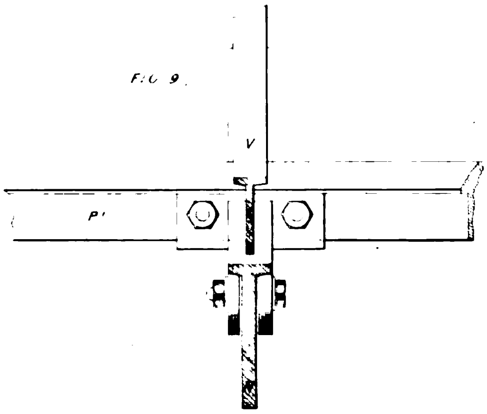


FIG 11

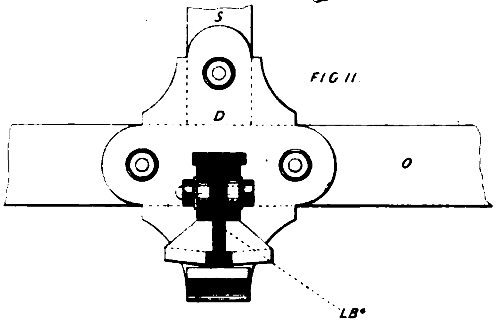
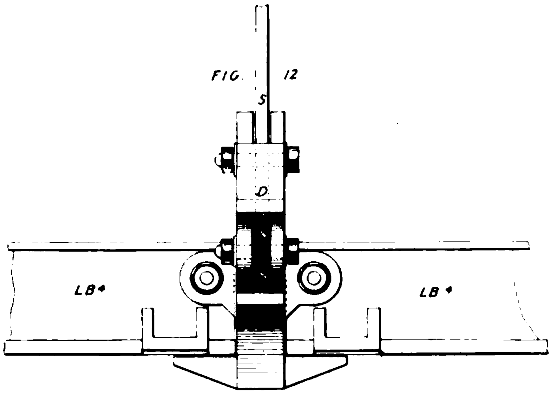


FIG 12



SCALE

INCHES 12 9 6 3 0 1

London Published by John W.

Digitized by Google

OF PARLIAMENT.

OUSE OF PEERS.

ILTIES

FIG. 6.

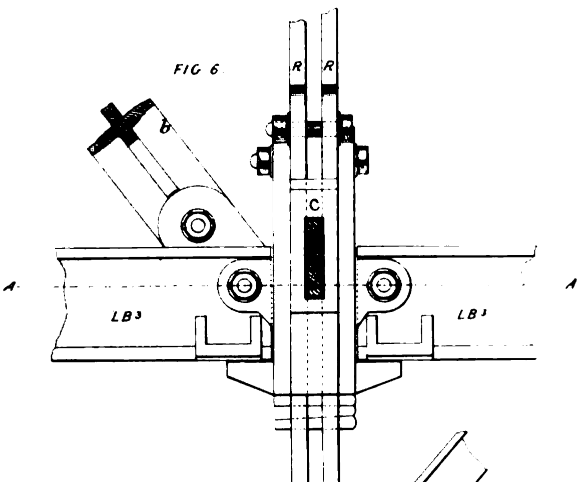


FIG. 7.

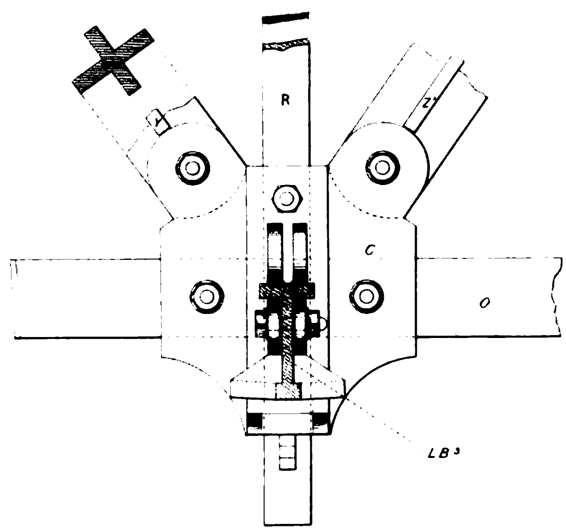


FIG. 10.

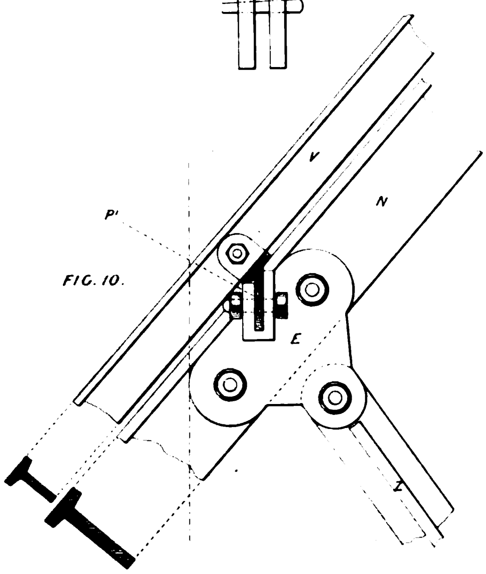


FIG. 8.

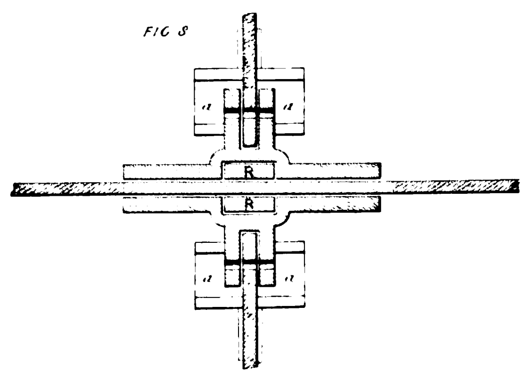


FIG. 13.

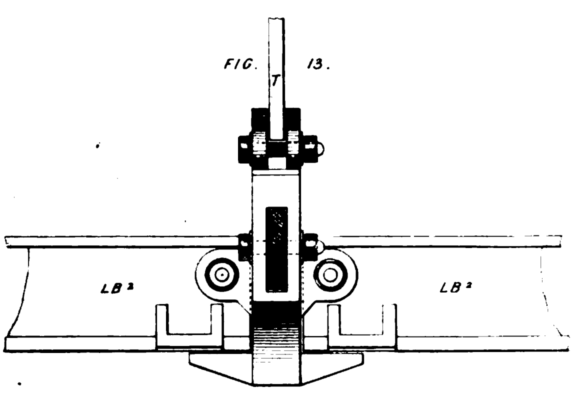
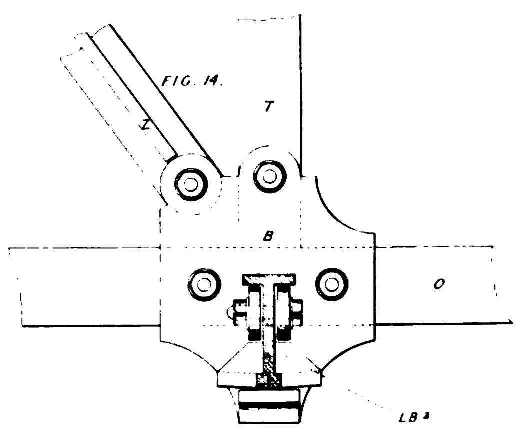


FIG. 14.



SCALE

2 3 4 FEET

B R Davies sculp

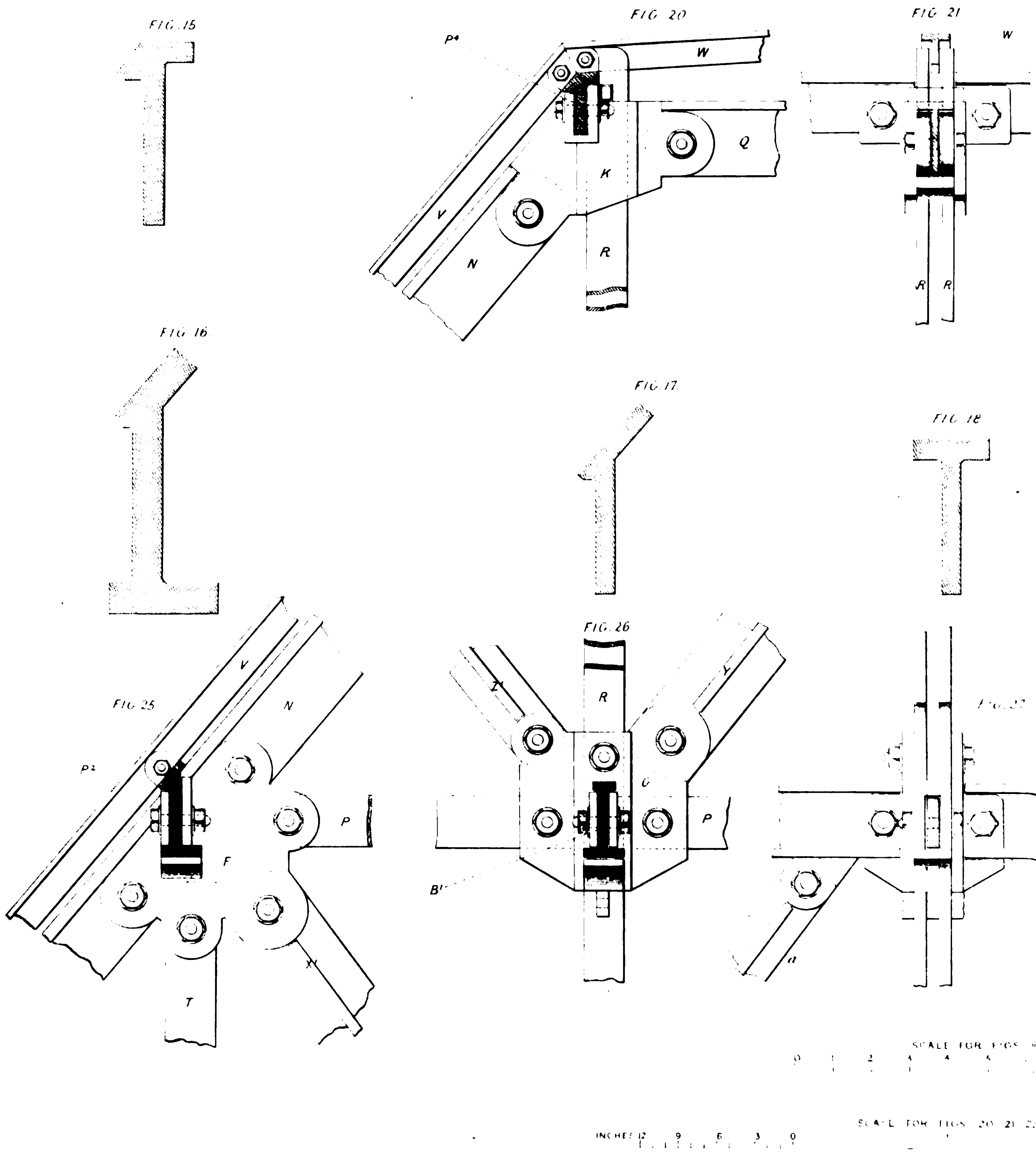
Weale, 59, High Holborn 1844.

Digitized by Google

Digitized by Google

NEW HOUSES O

ROOF OVER HO



London Published by John

Digitized by Google

OF PARLIAMENT.

OUSE OF PEERS.

LIES.

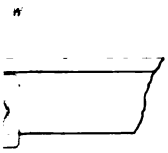


FIG. 22.

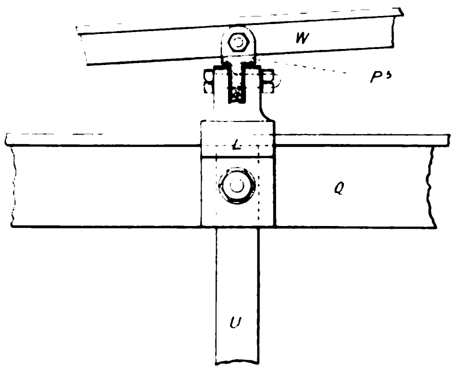


FIG. 23.

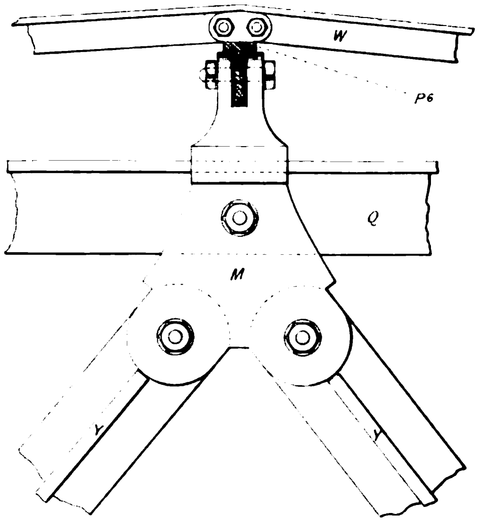


FIG. 24.

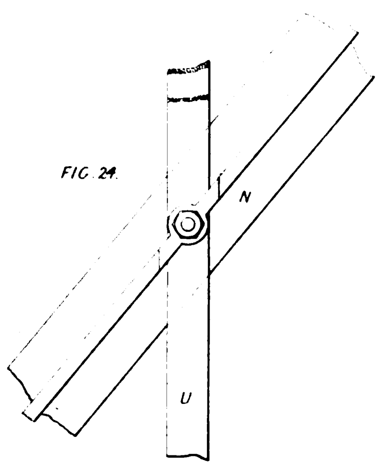
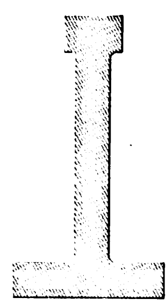


FIG. 19.



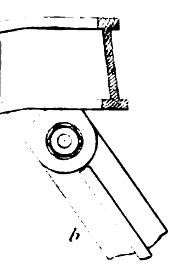


FIG. 28.

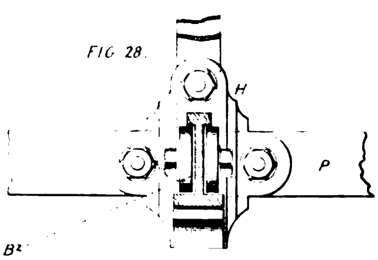
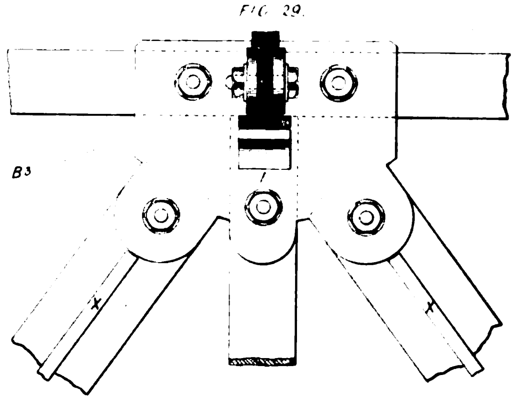


FIG. 29.



15 16 17 18 & 19
7 8 9 10 11 12 INCHES

22 23 24 25 26 27 28 & 29.
2 3 4 FEET

High Holborn 1844.

Digitized by Google

Digitized by Google

NOTICE

OF

THE BANGOR SLATE QUARRIES,

WITH SOME GENERAL REMARKS ON SLATE, AND THE VARIOUS MODES OF WORKING IT.

By SAMUEL HUGHES, C.E.

THESE magnificent quarries are situate about six miles south-east of Bangor, close to the road leading from that place to Bettws y Coed and the vale of Llangollen. Their geological position is in the vast formation of clay slate which extends through most of the Welsh counties; but although the name of this formation would imply the existence of slate over a large district of country, it must not by any means be supposed that slate of a proper quality for economic uses can be procured in every part of the clay slate formation. On the contrary, it is only where the lower stràta have been thrown up to a great height above their true place in the order of deposition, and where they can be reached by means of valleys stretching up into the bosom of the hilly country, that slate can be advantageously worked for economic purposes. The great quarry near Bangor occupies a position extremely favourable in every respect. The mountain which is being cut away by the operations of the slate quarrying, is called in Welsh, *y Bron*, which is a name signifying *breast* or *pap*, and is commonly given to any eminence with a round flowing outline, as distinguished from one which rises abruptly. The mountain of y Bron is on the side of a deep valley, in which flows the little river Ogwen, in a north-westerly direction, towards Lavan Sands, where it falls into the sea nearly opposite Beaumaris. The excavation of the slate quarry commences at a low level, but still a considerable height above the bed of the river, and has been pushed, during the last eighty years, probably about half a mile into the heart of the mountain, so as to present the appearance of an enormous amphitheatre —so vast as to throw into utter insignificance almost every other work of human

Digitized by Google

hands, and to excite profound reflections on the power and resources with which the Creator has endowed the human pigmies, who appear but as specks amid the recesses of the huge excavation. Looking up from the bottom of the valley towards the summit of the mountain, the sight of the quarry is truly imposing. The eye encounters one broad terrace after another, sweeping round in a vast arc, and each crowded with quarrymen, slate cutters, trucks, and piles of rough and squared slates. From the top to the bottom of the quarry there are sixteen of these terraces, the vertical height from one terrace to the other being thirty-nine feet, making the entire depth of the quarry about 624 feet.

In order to understand the method of working a slate quarry, it is necessary to refer to the peculiar mineralogical structure which distinguishes the clay slate system from those formations which occupy a more recent place in the scale of time. Besides the ordinary division of beds and joints which are common to all stratified deposits, it is found that the strata of slate are traversed by lines or planes, which separate the mass into an infinite number of laminæ. These laminæ do not coincide either with the joints or with the beds, which latter, as in ordinary cases, are in the plane of deposition; but they range at angles oblique to each of these, and most commonly in a vertical direction.

This peculiar structure of the slate rocks is termed, by geologists, the *slaty cleavage*, and it is this which, by affording the means of splitting up masses of slate into planes of any required thickness, so admirably adapts this substance for the various and important purposes to which it is applied in the building arts.

The origin of slaty cleavage has long been a subject of interesting discussion among geologists, and it now appears to be generally referred to electric or magnetic agency, operating either during or subsequent to the deposition of the slate rocks. This slaty cleavage appears to be quite independent of the planes of deposition, and whilst strata of sandstone, limestone, and beds of clay not so highly indurated as their representatives amongst the slates all exhibit distinct laminæ of deposition, it is found that these have been entirely obliterated in the slate rocks, if we except the evidence of colour, which is often extremely changeable, and in the case of a single block of slate, affords the only evidence of watery deposition which remains to attest the origin of those rocks.

The slaty cleavage continues uniform as to direction over extensive districts of country, and becomes very distinct towards the surface of the ground, where the slates are loose and easily separated from each other. It is in consequence of this slaty cleavage, and of the greater convenience with which slates can be detached from the side of a trench as compared with the method of raising their edges vertically, that the first operation in working a slate quarry is commonly that of extending a trench

Digitized by Google

or gullet into the side of the mountain containing the slate. When this trench has been extended to such a length that the rise of the mountain causes its depth to be about thirteen yards, another trench is commenced at the top of the former, and pushed on in a similar way towards the summit. At the same time, the widening of the lower gullet will be regularly effected by detaching blocks of slate, and thus the working of the quarry proceeds by successive gullets, one above the other, decreasing in width from the base of the mountain to the top. In the great quarry which forms the subject of this notice, the lower stages or terraces from which the slate is worked have lost the form of trenches, in consequence of the great extent to which they have been widened, and the excavation may with most propriety be likened to a vast amphitheatre, containing sixteen receding stages mounting one above the other, and each being worked for slate, so that the breadth of each stage remains almost constantly the same. At the top of the quarry, a gullet is in progress, which, in the course of a few years, will probably be extended to the same width as that of the lower stages, while others will rise even above the present summit of the quarry, which appears to be not so high within 400 feet as the top of the mountain.

About 1000 men are employed in this quarry at the present time, in the various operations of blasting the blocks with gunpowder, splitting the blocks with wedges into smaller and more manageable sizes, splitting and trimming the several kinds of roofing slate, in attending to the inclined planes and other machinery, in driving the trucks conveying the slate down to the harbour, &c.

In the upper part of the quarry, the slates are detached by means of crow bars, without the use of gunpowder, but in proportion to their depth, the slates increase in hardness, and require to be blasted. It is difficult to conceive, without witnessing it, the picturesque effect produced by this dangerous part of the miner's business. Each suspended by a rope from the edge of an upright crag of the rock, a great number of these brave fellows are seen busily engaged in drilling the holes to receive the charges of powder, and it is painful to say that accidents arising out of the dangerous nature of these blasting operations are of very frequent occurrence. The writer was told, on the occasion of a recent visit, that the number of persons killed by all kinds of accident at these works was not less, on the average, than one for every day in the year.

The slate rocks of this mountain, like those of many other similar districts, are traversed by several green stone dykes, in the neighbourhood of which the slates have been injured, and the cleavage structure entirely destroyed for a considerable breadth. These green stone dykes, being extremely hard, are a source of considerable trouble to the quarrymen, and expense to the proprietors. Usually they are blasted and cut away as the slate in their neighbourhood is quarried; but about the middle of this quarry there was a mass of green stone so hard and solid, that it was thought advisable to

Digitized by Google

work away the slates all round it, and to let the block of green stone remain. There it stands, therefore, to this day, a bare and isolated crag of basalt, forming a huge irregular obelisk, about 300 feet in height, and looking extremely ornamental, on account of its bright green colour, and the infinite number of transparent quartz crystals with which it is spangled over. The proprietor has lately determined on clearing away this block of green stone, which must have seriously impeded the working of the quarry, and accordingly there are numerous cradles slung all round it, each carrying a miner, who is boring a hole into it for the reception of a shot.

A great number of self-acting inclined planes are laid from one stage of the quarry to another, and by means of these, blocks of almost any size can be conveyed to the sheds for cutting and preparing the slates. A large drum and brake-wheel are fixed at the top of each inclined plane, to moderate the velocity of the descending trucks, and on almost every stage there are long ranges of sheds, in which the cutters are employed in shaping the slates according to the various sizes for which they are suitable. Our readers are of course aware that, in addition to the common kinds of roofing slate, known by the name of duchesses, countesses, ladies, &c., there is a superior kind of slate slab, varying from half an inch to two inches in thickness, adapted for chimney pieces, table tops, cisterns, mangers, billiard tables, patent roofing, flags for footpaths, and a variety of other important purposes. Slabs of this kind are sawn from the largest and soundest blocks, which come from the deeper parts of the quarry. With respect to the common-sized roofing slates, these are merely split to the proper thickness by the introduction of long wedge-shaped piece of iron, and are then cut to the largest size for which they are adapted, by being placed on a fixed steel edge, when a few blows from the cutting knife trims the edge of the slate to a true straight line.

Besides the machinery connected with the inclined planes, there is a large water-wheel in this quarry, which works a set of four pumps, for draining the lower part of it. The stream of water which turns the wheel has been brought from the side of the mountain, and carried across the quarry, in a wooden trunk, which is at present in a bad state of repair, and is altogether too rude a contrivance to be applied in connexion with the excellent arrangements which prevail in other parts of the work. When visiting this quarry, we could not help remarking that a great expense would be saved, by driving an adit from a low part of the Ogwen valley up to the bottom of the quarry, by which means it would be perfectly drained, without the present clumsy apparatus of water-wheel, trunk, and pumps. We had great pleasure in learning, before leaving the spot, that this very change had actually been determined on, and that a survey had recently been made to fix the position and course of the adit.

Digitized by Google

There are several forms of rail used in and about the quarry, in order that the trucks carrying the slate, the rubbish, &c., may traverse freely on any of the stages, and approach the face of any part of the rock. One of the best and most convenient forms for easy shifting appears to be that of a plain rolled bar, with a rounded top, and a short return of about an inch, like a peg, at each end of it. This peg fits into a hole cast in the chair or slipper, which reaches across from one rail to the other, the width between the rails being about two feet. Besides a great length of railroad laid down in and about the quarry, and on the immense mass of rubbish which is daily accumulating by the side of it, there is a permanent railway, about seven miles in length, laid from the quarry down to the port for shipping the slate, where a fleet of vessels is commonly waiting to receive cargoes.

The vast amount of capital embarked in these works, and the great profits they are supposed to realize, will appear almost equally incredible. It has been said, on good authority, that the late Lord Penryn expended £170,000 on the railroad and machinery connected with the quarry. It is understood that the late owner, Mr. Pennant, realized, for many years, a profit of about £80,000 per annum from the sale of slate produced at this quarry. The present proprietor is the Honourable Colonel Douglas Pennant, the member for Caernarvonshire, who changed his name of Douglas for that of Pennant, on marrying the daughter of the late proprietor.

We cannot conclude this notice without earnestly recommending the scene of it as well worth the trouble of a visit by any of our readers who may ever be thrown into the neighbourhood. The ride from Bangor to the quarry is extremely interesting, and presents a noble picture of Welsh scenery. From the summit of any of the lesser hills may be seen the dark and flowing outline of yet nobler eminences, such as the Carnedd Ddavid and Carnedd Llewellyn, whose frowning summits tower far above the slate mountain in which these works are situated; while beneath, the winding vales with their glittering streams, the mountain sides with their patches of dark wood; in the distance, the noble towers of Penryn Castle, the princely seat of Colonel Pennant; and yet further off, the entrance of the Menai Straits, contribute to fill up a landscape of surpassing beauty and interest. In the neighbourhood of Mr. Pennant's quarry, several others have recently been opened, and it is said with perfect success. Many years must elapse before they can be brought into the efficient state of their predecessor; but notwithstanding the disadvantages under which they labour from the confined scale of their operations, such has been the demand for slate, and such the daily increasing importance of the article, that all the speculations in slate quarrying which have been undertaken, both in Wales and Cornwall, are said to have been highly successful.

In addition to the numerous purposes to which slate is now applied, it appears

Digitized by Google

likely to come into extensive use in those parts of buildings where great strength and durability are required. In these qualities the massive blocks of slate, procured from quarries of repute, may challenge comparison with any building material in the world, not even excepting granite itself. Subjected to the severest tests of chemical science, and particularly to that exaggerated imitation of a natural destroying force called Mr. Brard's process for producing crystallization by boiling the specimen in a solution of Glauber's salts (sulphate of soda), it is found that slate loses nothing by this violent process, and betrays no symptoms of decomposition.

Although, from the large capital employed, the long period during which it has been worked, and the convenience of shipment, it is probable that the slate from this quarry is more extensively used than that produced in any other part of the country, yet it is said that there is slate in Westmoreland and in Cornwall of equally good quality. In particular, the Delabole quarries, near Tintagel, in the latter county, have long enjoyed a high reputation. It has been stated by an eminent experimental chemist, that the slate from Delabole is superior to the best Westmoreland slate, and also to that from Bangor, inasmuch as it admits of being split into thinner laminæ, and, whilst equally strong, weighs about two ounces to the square foot less than the Westmoeland, the thickness of each being about one eighth of an inch.

It is remarkable, that no slate quarries in this country are worked by underground galleries, or adits, similar to those for working coal mines. Considering the difficulty experienced in many slate quarries, with respect to the great mass of rubble, useless material, or overburden to be removed, or uncallowed, as it is called, before the good slate can be reached, it seems probable that mining for the lower beds of slate might be resorted to with advantage. It is true, that there is a considerable difference between the working of coal mines, where masses are broken down, and where breakage is of comparatively little consequence, and the quarrying of slate, in which it is important, in the first instance, to procure the masses in as large and entire a form as possible. This will obviously occasion a necessity for a different mode of working; and in all cases of mining for slate it would probably be necessary to have the working face as deep as that of the workings for coal in the Dudley coal field, where the famous ten yard coal is procured. Looking at the comparative prices of raw coal and unmanufactured slate at the works, it appears that the latter would amply pay for even an extra expense in mining labour. A ton of coal at the pit's mouth may be taken to be worth, on an average, about 7*s.*; whilst deducting from the ordinary selling prices of slate the expense of splitting and cutting them, their value in a raw state cannot be represented by a less sum than 24*s.* per ton, or more than three times the price of coal.

The most celebrated slate quarries in France are those of Angers and Charle-

Digitized by Google

ville. The former town is in the department of Maine et Loire, and is not only built upon the slate rock, but most of the houses are built of blocks of slate, those being used for building which are the thickest and most difficult to split. The quarries of Angers are open workings, and great inconvenience is experienced from the confined breadth to which the deepest part of the quarry is reduced, this being of course the situation of the best slate. This serious objection, which applies also to the Bangor quarry, would be obviated by subterranean workings, which might be made of any breadth, providing pillars were left to support the roof.

France contains also very famous slate quarries near the town of Rimogne, four leagues west of Charleville, on the banks of the Meuse, in the department of Ardennes. These quarries are worked by subterranean galleries, the main passage being about 400 feet in length, with several lateral galleries about 200 feet long on each side of the main gallery. These galleries are about sixty feet in height, but contain only about forty feet of good slate, the remaining twenty either consisting of quartz, or being injured by contact with volcanic substances.

The roof of the slate mine is composed of quartzose schistus, under which the bed of slate dips at the rate of three perpendicular to four horizontal. The slates from this mine are carried, by great labour, on the backs of men, who climb up a series of ladders to the surface of the ground.

In a memoir describing this quarry, in the Annales des Mines, M. Vialet, a French engineer, states, that by baking the slates in a brick kiln till they assume a red colour, he is able to double their natural hardness. He states that this process does not render the slates more brittle than before, but it adds so much to their hardness, that they ought to be formed and pierced before being put into the kiln.

The valuable article of slate appears to be still rarer in most other countries of Europe than in France and England. Switzerland is said to possess no slate, except in the valley of Sernst, in the canton of Glaris. Italy has only one quarry of slate, namely, that of Lavagna, in the state of Genoa, the slate from which is used for lining the cisterns in which olive oil is kept; a proof of the close texture and capacity for resisting the penetration of water which belongs to this slate.

There are several quarries of repute in the States of Germany, amongst which are those of Eisleben, in Saxony; of Ilmenau; of Mansfield, in Thuringia; and of Pappenheim, in Franconia[a].

[a] Pinkerton's Treatise on Rocks, Vol. I.

Digitized by Google

Digitized by Google

WOOLF'S PATENT STEAM ENGINE.

THROUGH the kindness of Mr. Philip Taylor, engineer of Marseilles, now on a visit in London, I am enabled to give the following rather curious document, which he accidentally met with. As the subject of the economy of fuel, and a given duty performed, is and always will be one of interest, it is considered not unimportant, even at the present time, to give it to our readers.

(COPY.)

This is to certify, that we, the subscribers hereto, were present on the premises of Woolf and Edwards, at Mill Street, Lambeth, on Friday, the 19th day of July, 1811, to witness an experiment made with a Steam Engine of Arthur Woolf's Patent construction, to ascertain how much wheat could be ground into flour by two pair of French bur stones of four feet diameter each, attached to the said engine, with a given quantity of coals; and that the following was the result:—

Worked the engine four hours and eleven minutes, and burnt three bushels of Newcastle coals, weighing 252 pounds.

During the above time, and with the above quantity of fuel, one pair of the above stones ground thirty-six bushels and forty-four pounds and a half, and the other pair twenty-four bushels and twenty-five pounds, making together sixty-one bushels and thirteen pounds and a half: and it is our opinion, that if the second pair of stones had been in as good order as the first, there would have been ground, with the above fuel, at least seventy-three bushels and a half. The wheat weighed fifty-seven pounds and a quarter per bushel.

JOSEPH BRAMAH, Engineer.
JOHN PEN, Engineer.
JOHN EDWARDS, Engineer.
PETER KEIR, Engineer.
JAMES MOORMAN, Engineer.
JAMES SMITH, Engineer.
RICHARD JACKSON, Engineer.
JOHN NORTON, Engineer.
JOSEPH MACHIN, Engineer.
JAMES BURTON, Engineer.

JOHN DICKSON, Engineer.
JOHN SHERWIN, Engineer.
THOMAS ROWNTREE, Engineer.
CHARLES FAIRBORNE, Mathematical Instrument Maker.
THOMAS JONES, Mathematical Instrument Maker.
RICHARD DEWDNEY, Miller.
GEORGE NICHOLAS, Miller.

LONDON, July 19th, 1811.

Digitized by Google

Digitized by Google

STEAM NAVIGATION.

So much has been stated as to the success and efficacy of steam power, as applied to navigation and for war purposes, in the United States, that we have added to our Papers the following Lecture, as written and published in America. We prefer giving the precise words, with the exception of a very short note in a subsequent page. We take leave to say, that the objects of science are best carried out by reference to such matters only as shall tend to illustrate the point in discussion.

A LECTURE ON THE LATE IMPROVEMENTS IN STEAM NAVIGATION AND THE ARTS OF NAVAL WARFARE, WITH A BRIEF NOTICE OF ERICSSON'S CALORIC ENGINE. DELIVERED BEFORE THE BOSTON LYCEUM, IN DEC. 1843, BY JOHN O. SARGENT.

Some five or six years ago, I was a spectator of the departure of the Great Western from the port of New York, on her first transatlantic voyage. The event excited universal interest. Quite a gala day was made on the occasion. When the hour of her departure approached, Castle Garden, and the battery, and the piers in the neighbourhood, on the North and East rivers, were crowded with their thousands of curious and anxious spectators. The numerous ships in the harbour displayed their national flags. Scores of sail-boats and row-boats were darting about among the large craft, with which the bay and rivers were alive. When this magnificent vessel started on her voyage, she was followed by a fleet of steam-boats laden with dense masses of human beings, while the floating streamers and gay music animated a scene which is, at all times, one of surpassing natural beauty.

The Great Western continued to come and go, with the regularity of the returning months, and her departure had, of course, ceased to be a subject of much more interest than that of an ordinary London packet.

Digitized by Google

On the 20th of October last, however, between two and three o'clock in the afternoon, the tide of life, that was pouring down Broadway towards the Battery, indicated that some spectacle was anticipated of similar interest with that which I have described. The Battery and the piers were again thronged with an expecting multitude. At her appointed hour, the Great Western came ploughing her way down the East river, under circumstances which manifested more than ordinary effort. She was enveloped in clouds of steam, and of dense black smoke; her paddle wheels were revolving with unusual velocity, leaving a white wake behind her, that seemed to cover half the river with foam:—and with her sails all set, she was evidently prepared to do her best in an anticipated race. As she passed the Battery, she was greeted with three hearty cheers, and a fair field with no favour was all that she seemed to challenge, and the least that all were willing to allow her.

She had left Castle Garden about a quarter of a mile behind her, when a fine model of a sailing-ship, frigate-like, appeared gliding gracefully down the North river, against the tide, without a breath of smoke or steam to obscure her path—with no paddle-wheels or smoke-pipe visible—propelled by a noiseless and unseen agency, without a rag of canvass on her lithe and beautiful spars—but at a speed that soon convinced the assembled thousands that she would successfully dispute the palm with the gallant vessel, celebrated throughout the world, and everywhere admitted to be the queen of the seas.

Such is the march of improvement in the arts. The new comer was the United States war-steamer Princeton. The agent by which she was moved was Ericsson's Propeller. She soon reached and passed the Great Western, went round her, and passed her a second time before they had reached their point of separation. In a moment, practical men began to speak lightly of their hitherto favourite paddle-wheel—and the propeller, that they had shrugged their shoulders at, and amused themselves with for some years of doubtful experiment, rose into altogether unexpected favour.

As confidential personal relations with Captain Ericsson, and an acquaintance with some of his friends, have made me familiar with the incidents of his professional career, I have thought that I could not more agreeably or more usefully occupy the hour allotted to me this evening, than by giving a brief account of an invention that is now exciting so much public interest; with a slight sketch of the man who is destined to rank, from his eminent attainments in the various branches of mechanical philosophy, and from the character and importance of the results he has already accomplished, with the first mechanicians of the age.

The principle of the propeller was first suggested to the inventor by the ana-

Digitized by Google

logies of nature, and a study of the means employed to propel the inhabitants of the air and deep. He satisfied himself that all such propulsion in nature is produced by oblique action; though, in common with all practical men, he at first supposed that it was inseparably attended by a loss of power. But when he reflected that this was the universal principle adopted by the great Mechanician of the universe, in enabling the birds, insects, and fishes to move through their respective elements, he knew that he must be in error. This he was soon able to demonstrate, and he became convinced, by a strict application of the laws which govern matter and motion, that no loss of power whatever attends the oblique action of the propelling surfaces applied to nature's locomotives.

After having satisfied himself on the theory of the subject, the first step of the inventor was the construction of a small model, which he tried in the circular basin of a bath in London. The model was fitted with a small engine, supplied with steam by a pipe leading from a steam-boiler over the centre of the bath, and descending to within a foot of the water line, where it was branched off by a swivel joint and connected with the engine in the boat. Steam being admitted in this pipe, the engine in the boat was put in motion, and motion was thus communicated to the propeller. To the great delight of the inventor, so perfectly was his theory borne out in practice, and so entirely were all his anticipations realized, that this model, though less than two feet long, performed its voyage about the basin, at the rate of upwards of three English miles an hour.

The next step in the invention was the construction of a boat forty feet long, eight feet beam, three feet draft of water, with two propellers, each of five feet three inches diameter. So successful was this experiment, that when steam was turned on the first time, the boat at once moved at a speed upwards of ten miles an hour, without a single alteration being requisite in her machinery. Not only did the boat attain this considerable speed, but its power to tow larger vessels was found to be so great, that schooners of one hundred and forty tons burthen were propelled by it at the rate of seven miles an hour; and the American packet ship Toronto, under the command of Captain Griswold, was towed in the river Thames, by this miniature steamer, at the rate of more than five English miles an hour through the water. This feat excited no little interest among the boatmen of the Thames, who were astonished at the sight of this novel craft moving against wind and tide without any visible agency of propulsion, and, ascribing to it some supernatural origin, united in giving it the name of the Flying Devil. But the engineers of London regarded the experiment with silent neglect: and the subject, when laid before the Lords of the British Admiralty, failed to attract any favourable notice from that august body.

Digitized by Google

Perceiving its peculiar and admirable fitness for ships of war, Ericsson was confident that their Lordships would at once order the construction of a war-steamer on the new principle. He invited them, therefore, to take an excursion in tow of his experimental boat. Accordingly, the gorgeous and gilt Admiralty barge was ordered up to the Somerset House, and the little steamer was lashed alongside. The barge contained Sir Charles Adam, Senior Lord of the Admiralty; Sir William Symonds, Surveyor of the British Navy; Sir Edward Parry, the celebrated commander of the second North Pole expedition; Captain Beaufort, Hydrographer, and others of scientific and naval distinction. In the anticipation of a severe scrutiny from so distinguished a personage as the chief constructor of the British navy, the inventor had carefully prepared plans of his new mode of propulsion, which were spread on the damask cloth of the magnificent barge. To his utter astonishment, as we may well imagine, this scientific gentleman did not appear to take the slightest interest in his explanations. On the contrary, with those expressive shrugs of the shoulder, and shakes of the head, which convey so much to the bystander without absolutely committing the actor,—with an occasional sly, mysterious, undertone remark to his colleagues,—he indicated very plainly that though his humanity would not permit him to give a worthy man cause for so much unhappiness, yet that "he could an if he would" demonstrate by a single word the utter futility of the whole invention.

Meanwhile the little steamer, with her precious charge, proceeded at a steady progress of ten miles an hour, through the arches of the lofty Southwark and London bridges, towards Limehouse, and the steam-engine manufactory of the Messrs. Seaward. Their lordships having landed and inspected the huge piles of ill-shaped cast iron, mis-denominated marine engines, intended for some of his Majesty's steamers; with a look at their favourite propelling apparatus, the Morgan paddle-wheel, they re-embarked and were safely returned to the Somerset House, by the disregarded, noiseless, and unseen propeller of the new steamer.

On parting, Sir Charles Adam, with a sympathizing air, shook the inventor cordially by the hand, and thanked him for the trouble he had been at in showing him and his friends this interesting experiment; adding, that he feared he had put himself to too great an expense and trouble on the occasion. Notwithstanding this somewhat ominous finale of the day's excursion, Ericsson felt confident that their lordships could not fail to perceive the great importance of the invention. To his surprise, however, a few days afterwards, a friend put into his hands a letter written by Captain Beaufort, at the suggestion, probably, of the Lords of the Admiralty; in which that gentleman, who had himself witnessed the experiment, expressed regret to state that their Lordships had certainly been very much disappointed at its result. The

Digitized by Google

reason for the disappointment was altogether inexplicable to the inventor: for the speed attained at this trial far exceeded any thing that had ever been accomplished by any paddle-wheel steamer on so small a scale.

An accident soon relieved his astonishment, and explained the mysterious givings-out of Sir William Symonds, alluded to in our notice of the excursion. The subject having been started at a dinner table when a friend of Ericsson was present, Sir William ingeniously and ingenuously remarked, that "even if the propeller had the power of propelling a vessel, it would be found altogether useless in practice, because, the power being applied in the stern, it would be absolutely impossible to make the vessel steer." It may not be obvious to every one how our naval philosopher derived his conclusion from his premises; but his hearers doubtless readily acquiesced in the oracular proposition, and were much amused at the idea of undertaking to steer a vessel when the power was applied in her stern.

But we may well excuse the Lords of the British Admiralty for exhibiting no interest in the invention, when we reflect that the engineering corps of the empire were arrayed in opposition to it; alleging that it was constructed upon erroneous principles, and full of practical defects, and regarding its failure as too certain to authorize any speculations even of its success. The plan was specially submitted to many distinguished engineers, and was publicly discussed in the scientific journals; and there was no one but the inventor who refused to acquiesce in the truth of the numerous demonstrations, proving the vast loss of mechanical power which must attend this proposed substitute for the old-fashioned paddle-wheel.

While opposed by such a powerful array of English scientific wisdom, the inventor had the satisfaction of submitting his plan to a citizen of the New World, who was able to understand its philosophy, and appreciate its importance. I allude to a gentleman well known to many who have enjoyed his liberal hospitality in a foreign land,—Mr. Francis B. Ogden, a native of New Jersey, for many years consul of the United States at Liverpool, and in that position reflecting the highest credit on the American name and character. Though not an engineer by profession, Mr. Ogden has been distinguished for his eminent attainments in mechanical science, and is entitled to the honour of having first applied the important principle of the expansive power of steam, and of having originated the idea of employing right-angular cranks in marine engines. His practical experience and long study of the subject,—for he was the first to stem the waters of the Ohio and Mississippi, and the first to navigate the ocean, by the power of steam alone,—enabled him at once to perceive the truth of the inventor's demonstrations. And not only did he admit their truth, but he also joined Captain Ericsson in constructing the first experimental boat to which I have alluded,

Digitized by Google

and which the inventor launched into the Thames, with the name of the Francis B. Ogden, as a token of respect for his transatlantic friend.

Other circumstances soon occurred, which consoled the inventor for his disappointment in the rejection of the propeller by the Lords of the British Admiralty. The subject had been brought to the notice of an officer of the navy of the United States, who was at that time on a visit to London, and who was induced to accompany the inventor in one of his experimental excursions on the Thames. I allude to Captain Robert F. Stockton, who is entitled to the credit of being the first naval officer who heard, understood, and dared to act upon the suggestions of Ericsson, as to the application of the propeller to ships of war. At the first glance, he saw the important bearings of the invention, and his acute judgment enabled him at once to predict that it was destined to work a revolution in naval warfare. In those who are not acquainted with the character of Captain Stockton, the great rapidity of his perception, his self-reliance, and the energy with which he prosecutes his purposes, it may excite some surprise to learn, that, after making a single trip in the experimental steam-boat, from London Bridge to Greenwich, he ordered the inventor to build for him forthwith two iron boats for the United States, with steam machinery and propeller on the plan of this rejected invention. "I do not want," said Captain Stockton, "the opinions of your scientific men; what I have seen this day satisfies me." It is due to Captain Stockton to state that his whole course in regard to this invention, and the introduction of it into this country, has been in accordance with the spirit of this remark.

At a dinner given on this occasion at Greenwich, Captain Stockton, in his happy style, made several predictions and promises in respect to the new invention, all of which have since been realized. To the inventor, he said in words of no unmeaning compliment, "We'll make your name ring on the Delaware, as soon as we get the propeller there." The Princeton was launched into the Delaware, and the Ericsson steam-boat line is now carrying nearly the whole of the freight between Philadelphia and Baltimore, and Captain Stockton's several iron propeller boats may be seen every day on the Delaware, carrying the rich mineral products of Pennsylvania to the East.

But not only did Captain Stockton order, on his own account, the two iron boats to which I have referred; he at once brought the subject before the government of the United States, and caused numerous plans and models to be made at his own expense, explaining the peculiar fitness of the new invention for ships of war. So completely persuaded was he of its great importance in this aspect, and so determined that his views should be carried out, that he boldly assured the inventor that the

Digitized by Google

government of the United States would test the propeller on a large scale; and so confident was Ericsson that the perseverance and energy of Captain Stockton would sooner or later accomplish what he promised, that he at once abandoned his professional engagements in England, and set out for the United States. Circumstances delayed, for some two years, the execution of their plan. With the change of the federal administration, Captain Stockton was first able to obtain a favourable hearing; and under the auspices of the present administration, the experiment of the Princeton has been made, and has been successful.

It is due to the inventor to mention that the propeller, as successfully applied in the Princeton, is the same precisely in construction with that of the Francis B. Ogden; not merely in theory, but in its minute practical details. There is now a propeller in the Phœnix Foundry, in New York, brought over by Captain Ericsson, in the British Queen, in 1839, which, in all its essential parts, is a fac-simile of that in the Francis B. Ogden, and of that in the Princeton.

The circumstances, then, under which this invention was devised and prosecuted, the perseverance with which it was followed up by Ericsson, through all discouragement and neglect, and its ultimate success in its precise original shape, prove it to have been the result, not of a happy accident, but of patient reflection and scientific calculation. It was not hit upon, but was wrought out; it was not suggested, but elaborated; demonstrated in theory to the inventor's own satisfaction, before it was submitted to the test of a successful experiment.

In further illustration of this fact, and before proceeding to give a more particular account of the Princeton and the propeller, I will present a brief personal sketch of the inventor, that cannot fail to possess the interest of novelty, at least, to all; and may gratify such of the audience as indulge a natural curiosity in tracing the progress of a professional career, from its dawn to its meridian, without waiting for its close.

John Ericsson was born in 1803, in the province of Vermeland, among the iron mountains of Sweden. His father was a mining proprietor, so that the youth had ample opportunities to watch the operation of the various engines and machinery connected with the mines. These had been erected by mechanicians of the highest scientific attainments, and presented a fine study to a mind of mechanical tendencies. Under such influences, his innate mechanical talent was early developed. At the age of ten years, he had constructed with his own hands, and after his own plans, a miniature saw-mill; and had made numerous drawings of complicated mechanical contrivances, with instruments of his own invention and manufacture.

In 1814, he attracted the attention of the celebrated Count Platen, who had

Digitized by Google

heard of his boyish efforts, and desired an interview with him. After carefully examining the various plans and drawings which the youth exhibited on this occasion, the count handed them back to him, simply observing in an impressive manner, "Continue as you have commenced, and you will one day produce something extraordinary." Count Platen was the intimate personal friend of Bernadotte, the King of Sweden, and was regarded by him with a feeling little short of veneration. It was Count Platen who undertook and carried through, in opposition to the views of the Swedish nobility, and of nearly the whole nation, that gigantic work, the Grand Ship Canal of Sweden, which connects the North Sea with the Baltic. He died Viceroy of Norway, and left behind him, in the north of Europe, the reputation of one of the greatest men of the century. The few words of kind encouragement, which he spoke on the occasion to which I have referred, sank deeply into the mind of the young mechanician, and confirmed him in the career on which he had entered.

Immediately after this interview, young Ericsson was appointed a cadet in the corps of engineers, and after six months' tuition, at the age of twelve years, was appointed nivelleur at the Grand Ship Canal, under Count Platen. In this capacity, in the year 1816, he was required to set out the work for more than six hundred men. The canal was constructed by soldiers. He was at that time not tall enough to look through the levelling instrument; and in using it he was obliged to mount upon a stool, carried by his attendants for that purpose. As the discipline in the Swedish army required that the soldier should always uncover the head in speaking to his superior, gray-headed men came, cap in hand, to receive their instructions from this mere child. While thus employed in the summer months, he was constantly occupied during the winter with his pencil and pen; and there are many important works on the canal constructed after drawings made by Ericsson at this early age. During his leisure hours, he measured up and made working drawings of every implement and piece of machinery connected with this great enterprise; so that, at the age of fifteen, he was in possession of accurate plans of the whole work, drawn by his own hand.

His associations with military men on the canal had given him a tendency for military life, and at the age of seventeen he entered the Swedish army as an ensign, without the knowledge of his friend and patron Count Platen. This step excited the indignation of the count, who tried to prevail upon him to change his resolution; but finding all his arguments useless, he terminated an angry interview by bidding the young ensign to "go to the devil." The affectionate regard which he entertained for the count, and gratitude for the interest taken by him in his education, caused

Digitized by Google

the circumstances of this interview to make a deep impression upon Ericsson, but were not sufficient to shake his determination.

Soon after the young ensign had entered upon his regimental duties, an affair occurred which threatened to obscure his hitherto bright prospects. His colonel, Baron Koskull, had been disgraced by the king, about the time that he had recommended Ericsson for promotion. This circumstance induced the king to reject the recommendation. The colonel was exceedingly annoyed by this rejection, and having in his possession a military map made by the expectant ensign, took it to his royal highness the crown prince Oscar, and besought him to intercede for the young man with the king. The prince received the map very kindly, expressing great admiration of its beautiful finish and execution, and presented himself in person with it to the king, who yielded to the joint persuasion of the prince and the map, and promoted the young ensign to the lieutenancy for which he had been recommended.

About the time of this promotion, the government had ordered the northern part of Sweden to be accurately surveyed. It being the desire of the king that officers of the army should be employed in this service, Ericsson, whose regiment was stationed in the northern highlands, proceeded to Stockholm, for the purpose of submitting himself to the severe examination then requisite to precede the appointment of government surveyor. The mathematical education which he had received under Count Platen now proved very serviceable. He passed the examination with great distinction, and in the course of it, to the surprise of the examiners, showed that he could repeat Euclid verbatim; not by the exercise of the memory, which in Ericsson is not remarkably retentive, but from his perfect mastery of geometrical science. There is no doubt that it is this thorough knowledge of geometry, to which he is indebted for his clear conceptions on all mechanical subjects.

Having returned to the highlands, he entered on his new vocation with great assiduity; and, supported by an unusually strong constitution, he mapped a larger extent of territory in a given time than any other of the numerous surveyors employed on the work. There are yet in the archives of Sweden, detailed maps of upwards of fifty square miles made by his hand. Neither the great labours attending these surveys, nor his military duties, could give sufficient employment to the energies of the young officer. He now commenced the arduous task of compiling a work on canals, to be illustrated by sixty-four large plates, representing the various buildings, machines, and instruments connected with the construction of such works. The part assigned to him in this enterprise was nothing less than that of constructing all the drawings, as well as of engraving the numerous plates; and as all the plates were to be executed in the style of what is called machine-engraving, he undertook to con-

Digitized by Google

struct a machine for the purpose, which he successfully accomplished. This work he prosecuted with so much industry in the midst of his other various labours, that, within the first year of its commencement, he had executed eighteen large plates, which were pronounced by judges of machine-engraving to be of superior merit.

His associate in this undertaking was a German engineering officer, Major Pentz, who wrote the text in the German language in preference to the Swedish, in order to secure a wider circulation. Other labours prevented the immediate completion of this work; and so rapid is the improvement in civil engineering, that the lapse of a very few years, from the time of the intended publication, would have rendered it of but little practical utility.

While thus variously occupied, being on a visit to the house of his colonel, Ericsson on one occasion showed his host, by a very simple experiment, how readily and by what simple means mechanical power may be produced, independently of steam, by condensing flame. His friend, being himself a lover of the sciences, was much struck by the beauty and simplicity of the experiment, and prevailed upon Ericsson to give more attention to a principle which he considered highly important. The young officer accordingly made some experiments on an enlarged scale, and succeeded in the production of a motive power equal to that of a steam engine of ten horse. So satisfactory was the result of these experiments, from the compact form of the machine employed, as well as the comparatively small consumption of fuel, that he conceived the idea of at once bringing it out in England, the great field for all mechanical inventions.

Ericsson accordingly, through his colonel, obtained leave from the king to visit England, where he arrived on the eighteenth of May, 1826. He there proceeded to construct a working engine on the principle to which I have referred; but soon discovered that his Flame Engine, when worked by the combustion of mineral coals, was a different thing from the experimental model he had tried in the highlands of Sweden, with fuel composed of splinters of fine pine wood. Not only did he fail to produce an extended and vivid flame, but the intense heat of the mineral coals so seriously affected all the working parts of the machine, as soon to cause its destruction. These experiments, it may well be supposed, were attended with no trifling expenditure; and, to meet their demands upon him, our young adventurer was compelled to draw on his mechanical resources.

Invention now followed invention in rapid succession, until the records of the Patent Office, in London, were enriched by the drawings of the remarkable steam-boiler on the principle of artificial draft; to which principle we are mainly indebted for the benefits conferred on civilized life by the present rapid communication by rail-

Digitized by Google

ways. In bringing this important invention before the public, Ericsson thought it advisable to join some old and established mechanical house in London, and accordingly he associated himself with John Braithwaite, a name favourably known in the mechanical annals of England. This invention was hardly developed, when a favourable opportunity was presented for testing it in practice. The directors of the Liverpool and Manchester railway, before erecting the stationary engines by which they had intended to draw their passenger and freight carriages, determined to appeal to the mechanical talent of the country, in the hope of securing some preferable mode of transit. A prize was accordingly offered, in the fall of 1829, for the best locomotive engine, to be tested on the small portion at that time completed of the railway. Sufficient publicity not having been given to their advertisement, Ericsson was not aware that any such prize had been offered, until within seven weeks of the day fixed for the trial. Unwilling to permit the occasion to escape him, he was not deterred by the shortness of the time, but, applying all his energies to the task, planned the engine, executed the working drawings, and caused the patterns to be made, and the whole machine completed within the seven weeks. The day of trial arrived. The competing engines were on the ground, and the novelty of the race had attracted an immense concourse of people. Both sides of the railway, for more than a mile in length, were lined with thousands of spectators. There was no room for jockeying in such a race, for inanimate matter was to be put in motion, and that moves only in accordance with immutable laws. The signal was given for the start. Instead of the application of whip and spur, the gentle touch of the steam-valve gave life and motion to the novel machine. Up to that period, the greatest speed at which man had been carried along the ground was that of the racehorse; and no one, of the multitude present on this occasion, expected to see that speed surpassed. It was the general belief that the maximum attainable by the locomotive engine would not much exceed ten miles. To the surprise and admiration of the crowd, however, the Novelty steam carriage, the fastest engine started, guided by its inventor, Ericsson, assisted by John Braithwaite, darted along the track at the rate of upwards of fifty miles an hour!

The breathless silence of the multitude was now broken by thunders of hurras, that drowned the hiss of the escaping steam and the rolling of the engine wheels. To reduce the surprise and delight excited on this occasion to the universal standard, —and as an illustration of the extent to which the value of property is sometimes enhanced by the success of a mechanical invention,—it may be stated that when the Novelty had run her two miles and returned, the shares of the Liverpool and Manchester railway had risen ten per cent.

Digitized by Google

But how easily may the just expectations of an inventor be disappointed! Although the principle of the steam-boiler which gave to the Novelty engine such decided superiority in speed, is yet retained in all locomotive engines,—I mean the principle of artificial draft,—yet the mode of producing this draft in our present engines is far different from that introduced by Ericsson, and was discovered by the merest accident; and so soon was this discovery made, after the successful display of the Novelty engine, that the inventor had no time to derive the least advantage from its introduction.

To him, however, belongs the credit of having first disproved the correctness of the once established theory, that it was absolutely necessary that a certain extensive amount of surface should be exposed to the fire, to generate a given quantity of steam. The remarkable lightness and compactness of the new boiler, invented by Ericsson, have led to the employment of steam in many instances in which it had been previously inapplicable. Among these I would only mention the steam fire-engine constructed by him in conjunction with Mr. Braithwaite, about the same time with the Novelty, and which excited so much interest in London at the time the Argyle Rooms were on fire. A similar engine of greater power was subsequently constructed by Ericsson and Braithwaite, for the king of Prussia, which was mainly instrumental in saving several valuable buildings at a great fire a few years ago at Berlin. For this invention Ericsson received, in 1842, the large gold medal offered by the Mechanics' Institute of New York, for the best plan of a steam fire-engine.

It would not consist with the limits or the design of this lecture, to mention the numerous inventions devised by Captain Ericsson during his residence in England,—my main object being to describe, very briefly, the propeller in its application to ships of war. In natural connexion with which, I shall take occasion to comment on an invention which has been for many years the favourite project and study of Captain Ericsson, and the perfecting of which will confer inestimable benefits on mankind.

Before resuming the topic with which I commenced, and returning to the spectacle which suggested the lecture of this evening, I will attempt a slight description of the mechanical construction of the propeller, and notice some of the objections to it which have been suggested during the many years of opposition, ridicule, and neglect through which it has been forcing its way into public use.

The Ericsson propeller is composed of a series of spiral plates attached to the outside circumference of a short cylinder; which is supported by two or more winding or twisted spokes. The mere description suggests very obvious differences between this machine and the Archimedean Screw, which is simply a thread or spiral blade coiled round an axis; and yet the error prevails extensively that the two are one and

Digitized by Google

the same thing. The propeller is placed at the stern of the vessel, and instead of revolving in a plane parallel to the keel, like the ordinary paddle-wheel, it moves in a plane at right angles, on a shaft or axis parallel to the keel. In all vessels having a large draft of water, the propeller acts entirely below the surface; and in vessels of a light draft, it is only partially immersed.

I have already stated that the principle of Ericsson's propeller is that of oblique action; very much resembling the action employed by nature in her various contrivances of propulsion through the air and water, such as in the wings of birds and insects, and in the tails of fishes. But though this general similarity exists between the oblique action in the propelling surfaces of this machine and that of the propelling surfaces alluded to in nature, yet there is this important difference; that, whilst there is a reciprocating movement given to them by the latter, a rotary movement is given to them in the propeller.

But if this mode is preferable, why has it not been employed by nature? It is obvious that, in an animal, the rotary movement would twist and destroy the blood-vessels and integuments connecting the propelling apparatus to the main body, and cannot, therefore, be employed. Human contrivance, however, may well have the advantage over that of nature in a single aspect. The one thing for which it is designed, and that only, it can execute; whilst the motive machines of nature are capable of discharging a thousand functions at the same time.

It has formed a popular objection to the propeller, that there is a loss of power unavoidably consequent on the oblique action. It is a well established principle in hydrostatics, that the force of fluids is always directed at right angles to the surface on which it acts. From this it follows that the force of the water, exerted against the oblique plates of the propeller, depends upon the superficial measurement. It may at once be admitted that the whole amount of the force thus acting on the plates, will not, in consequence of their oblique position, be exerted in urging the vessel ahead. Now this admission, to an unreflecting observer, might lead to the conclusion that there is a loss of power; but the same reasoning, which shows that the vessel is not urged ahead by the whole force exerted on the plates, likewise proves that this whole force does not counteract the power of the engine employed in turning the propeller. The erroneous conclusion, then, as to the loss of power, arises from overlooking this important fact; for, in the ratio that the propelling force imparted to the vessel is less than the actual pressure on the plates, in the very same ratio will the engine power requisite to turn the propeller be less than the force of the water exerted against the plates.

It has been asserted by many engineers of reputation, that the centrifugal ten-

Digitized by Google

dency produced by the revolution of the propeller, would cause the water constantly to recede from the centre, and thereby render the propelling surfaces inefficient. This tendency the inventor of the propeller has obviated, by the introduction of the short cylinder, or broad hoop, to which the spiral plates are attached. The water tending to fly off from the centre is effectually intercepted by this hoop.

In the Princeton, the cylinder of the propeller is eight feet in diameter, and twenty-six inches long; and the extreme diameter described by the outer edges of the spiral plates is fourteen feet. It is manufactured wholly of composition metal, the copper of the vessel, in connexion with the sea water, exciting a galvanic action which corrodes iron and renders it inapplicable for this purpose.

The steam machinery of the Princeton is quite as worthy of observation as her propeller. It is evidently not enough, in a ship of war, that the propeller alone should be placed below the water line; it is indispensable that the whole machinery should be placed out of the reach of shot. The ordinary steam engine is too bulky to admit of this location, and Captain Ericsson has invented and constructed an engine upon a novel principle, by which he has been able to effect this most desirable object. Any one, of skill or knowledge in mechanics, will be instantly struck by this beautiful engine as the most remarkable feature in the ship; in view of the vast power that it embodies in so small a compass, and the perfect symmetry and exquisite proportions of all its working parts. It has been patented in England, and in this country, by Captain Ericsson, under the name of the semi-cylindrical steam engine. It differs from other engines in the construction and operation of its working cylinders. In the place of complete cylinders, semi-cylinders are employed; the pistons of which, instead of being circular, and traversing from end to end of the cylinder, consist of parallelograms, having a radial or vibrating movement, similar to that of a pendulum, the centre of motion being the centre of these semi-cylinders. The semi-cylinders are placed longitudinally in the very bottom of the vessel, and parallel to the line of keel. Motion is given to the propeller shaft by means of short connecting rods, attached to vibrating crank levers on the axes of the vibrating pistons; and the latter are made to reciprocate by the admission of steam, alternately, on opposite sides, as in ordinary engines.

This semi-cylindrical engine of Ericsson marks an epoch in the history of steam engines. It is so compact that it occupies only one-eighth of the bulk of the British marine engine of corresponding power, and is less than one-half the weight. By a peculiar construction, the moving parts have been rendered so extremely light, that the quantity of matter to be kept in motion is hardly one-sixth that of the engine to which I have alluded. This lightness and simplicity of arrangement enable Ericsson

Digitized by Google

to give a direct movement to the propeller shaft, without the intervention of cog wheels and other gear for multiplying the speed, resorted to in the Great Britain steam ship, and indispensable in all steamers propelled by the Archimedean screw. The engines of the Great Britain, owing to their cumbrous nature, must be worked at a speed only one-fourth that of the screw—that is, the screw will perform four revolutions to one of the engine.

The next peculiarity to be noticed in the Princeton, is the absence of the ordinary tall smoke pipe, employed to produce the draft for keeping up combustion in the furnaces of the boilers. The smoke pipe has hitherto formed an insuperable objection to a steamer as a ship of war; for the moment that it is carried away, the efficiency of the engines ceases from want of steam. The draft in the boilers of the Princeton is promoted by means of blowers, placed in the bottom of the vessel, and is quite independent of the height of the smoke pipe, which is only carried about five feet above the deck of the ship. If this inconsiderable projection should become partially deranged by a shot, the draft kept up by the blowers will continue as efficient as before.

It is not out of place here to observe, that Ericsson was the first to apply to marine engines centrifugal blowers, now so common in this country in all boilers using anthracite coal. In the year 1831, he applied such a blower, worked by a separate small steam engine, to the steam packet Corsair of one hundred and twenty horse power, plying between Liverpool and Belfast.

But Captain Ericsson has not merely furnished the Princeton with this efficient and secure means of propulsion, he has also furnished her with instruments which tend to render the large guns introduced by Captain Stockton extremely formidable ordnance. The Princeton has two of these guns. One of them was made in England, and is of about seven tons weight; the other was forged by Ward and Co., and finished at the Phœnix Foundry in the city of New York. The latter is said to be the largest piece of wrought iron in the world. It weighs ten tons, has a bore of twelve inches, and carries a ball of two hundred and thirteen pounds.

Powerful as this gun is, from its large calibre, yet it would obviously be of little practical use without the means of handling, managing and directing it; and such means have been devised by the same mind which conceived the propeller and the steam engine of the Princeton. These are a carriage of peculiar construction; a novel lock; and an instrument for measuring distances at sea. The carriage obviates the difficulties arising from the immense recoil of the gun, and renders it, notwithstanding its vast weight, readily manageable by a small number of hands. It is made of wrought iron.

Digitized by Google

The lock to which I have referred, is constructed on principles by which the common law of gravitation, in connexion with the rolling of the sea, is made subservient in discharging the gun at any desired elevation without human interference. The idea of this lock occurred to Captain Ericsson in the year 1828, and he then constructed one which was exhibited to the head of the British Ordnance Department, Sir Henry Vane. This gentleman was very much struck with the important object of the invention, and offered to appoint a board of officers to test it in practice, and to report upon it. But as the test could not be satisfactorily applied without divulging the secret of the invention, Captain Ericsson desired to have an agreement executed, binding the government to make him a suitable remuneration, in the event of the trial proving successful. Such a course did not coincide altogether with the views of Sir Henry Vane, and the inventor declined further negociation; preferring to lock up his instrument in an iron safe, where it remained until the year 1839, when his acquaintance with Captain Stockton induced Ericsson to believe him the proper person to bring out the invention. Nor was he deceived, for Captain Stockton saw at a glance its whole practical bearing and importance. This lock will be applied to the large wrought iron guns of the Princeton, and cannot fail, I am assured, to direct them with unerring certainty, even in a heavy seaway.

Of the distance instrument I must say a word. The point-blank range of a gun, it is well known, is very limited; and, consequently, when the enemy is at a distance exceeding half a mile, it becomes necessary to give a certain elevation to the gun, in order to counteract the effect of gravitation on the ball. This elevation depends entirely on the distance of the object to be aimed at; and unless that be accurately known, the proper elevation cannot be given with any degree of accuracy. Various contrivances have been from time to time suggested by naval men, for measuring distances at sea, but hitherto the result has been mere guesswork. The fertility of Ericsson's mechanical genius has, however, at length accomplished this great desideratum, by an instrument calculated to measure all distances at sea from four hundred and fifty to four thousand yards. It is based upon unerring and simple mathematical principles, and enables the observer to measure any required distance in a few seconds; and the result being read off by inspection, there is no liability of error.

In view, then, of the many advantages possessed by the Princeton, I will recur to the spectacle with the delineation of which I commenced this lecture, and indulge for a moment in the reflections and speculations which it naturally suggests. In the way of steam navigation, the Great Western is thus far the boast of European skill and science. Neither the government of France nor of England, with their immense steam navies, has produced any thing superior in speed, beauty, or security. And

Digitized by Google

yet, how comparatively cumbrous, unmanageable, and exposed are her steam machinery and her paddle-wheels! A single shot well directed would destroy her capacity of propulsion by steam, and leave her at the mercy of the elements. Thus crippled, her sole dependence must be upon her canvass, and in a calm she would lie an idle hulk upon the waters; and with wind, her canvass would be of little use to her, while oppressed by the dead weight of her fuel and machinery, and retarded by the resistance of her motionless paddle-wheels. And what is true of the Great Western, is equally true of whole fleets of steamers that have been constructed, by the governments of Europe, with a partial view to objects of commerce and communication, but with the ulterior and contingent purposes of aggressive or defensive warfare.

Turn now to the Princeton, and look at her, not with reference to her armament, which in this aspect is of secondary interest, but to her means of propulsion alone. Her steam machinery and propelling apparatus are placed entirely below the water line; while the contrivance, by which motion is communicated to the propeller, is so simple as almost to preclude the possibility of derangement, and is inaccessible to any external agent of injury. Strip her of sails and yards, cut down her masts, riddle her hull with shot, lay her bare fore and aft to the water line—her engine still remains uninjured, the boiler still generates steam, and her moving power still continues undiminished. It is universally admitted that the introduction of steam upon the ocean will produce a great change in maritime warfare; but the principles developed in the Princeton will work an entire revolution.

Steamers, as hitherto constructed, may be well enough employed in maintaining communication between distant shores and distant fleets, or in towing ships of war into position, but they are not capable of mingling in the combat. It is difficult, however, to imagine a more formidable or more safe machine of warfare than the Princeton. Not only can she act upon data of seasons and distances, with an accuracy that winds or waves can but little disturb, but she can move secretly and silently upon her prey. There is no cloud of smoke to track her path by day, and the noiseless action of her submerged propeller gives no warning to the enemy of her approach by night. Tempests cannot thwart her. Calms cannot delay her progress. By the location of her moving power below the water line, it is protected from the missiles of the enemy. She can select her own time and place of attack. She can never be forced into an engagement, and in a thousand situations in which the crippled line-of-battle ship or the crippled paddle-wheel steamer would be at the mercy of the enemy, the Princeton may retire from a superior foe, and, with her unimpaired moving power, retain a position from which she may mark her very retreat with destruction and death.

Digitized by Google

Whatever may have been the cause of her policy, whether it is the consequence of accident or foresight, it is certainly fortunate for our own country, that she has not followed the example of the leading European powers in their bold expenditures and experiments in the navigation of the ocean by steam. Millions on millions of pounds have been disbursed by those governments, in the construction of steam fleets, which, in view of the improvements that physical science has successfully introduced in the Princeton, may answer as tenders and transport ships, but must prove utterly useless in a naval engagement. While an ordinary sailing man-of-war may remain efficient, after receiving a dozen broadsides, a shot in the right place would completely disable the proudest of the war steamers that now float under the banners of France or of England.

The construction of the Princeton, and the reservation of our means to be expended on the principles that have been successfully applied in that beautiful steamer, place us, in regard to steam navigation, in a better position than any other nation of the globe. It may safely be said, that the Princeton alone is more than a match for a fleet of paddle-wheel steamers. I am informed that Captain Stockton, conscious of the advantages which the genius of Ericsson has given to steam ships, declared on a recent occasion, that, with twenty steam frigates on the new plan, he would engage to take possession of the British Channel and to blockade London itself[a].

But we should have little cause to contemplate with pleasure the improvements which I have thus imperfectly described, if they could be made to minister merely to the arts of warfare. It is in a different service they assume the most interesting aspect; a service in which they cannot fail to extend the blessings of civilization, and promote the welfare of the great family of man.

I have hitherto considered the propeller merely in connexion with ships of war; but it must prove of far greater importance in increasing the facilities of pacific intercourse, and in establishing a certain and rapid communication between the kindred nations of the globe. A great change in this respect has already been effected by the application of steam to the navigation of the ocean; but in consequence of the imperfect action of the paddle-wheel, we have hitherto failed to accomplish a successful co-operation of the powers of wind and steam. By the substitution of the propeller, these two powers may be harmoniously combined. It is well ascertained that sails cannot be used to any great advantage in ordinary steam ships. The action of the wind upon the sails careens the vessel; and thus, one paddle-wheel is immersed, while the other is lifted entirely out of the water. A great retardation of speed is the obvious consequence. But the propeller continues

[a] Bombast!—Ed.

Digitized by Google

equally as efficient when a ship is upon her beam ends, as when she is perfectly upright; and thus, the full power of the engines may be made to operate, at the same moment, with the entire force of the wind. There is no situation of the ship in which there is any necessary conflict of these two great agencies of propulsion. In the event of any derangement of the machinery, or of any circumstances which should require an economical expenditure of fuel, the propeller may be readily disengaged, and the vessel proceed by the aid of her canvass alone. In the Princeton, for instance, such is the connexion between the engines and the propeller, that by simply touching a lever the propeller is at once liberated. Thus released, it revolves freely on the shaft, and causes a very inconsiderable resistance to the progress of the ship.

Such indeed are the lightness and compactness of the propeller, and such is the simplicity of the engine by which it is set in motion, that it may well be applied to ordinary sailing vessels as an auxiliary; and it is in this form, doubtless, that the invention is destined to promote the greatest and most beneficial changes in navigation. Indeed it requires but little boldness to predict that the time is not far distant when all vessels, intended for ocean navigation, will be provided with this auxiliary power; and thus proceed steadily to their respective points of destination, with a certainty, regularity, and dispatch that will add greatly to the results of human exertion.

In natural connexion with the propeller, I now propose to take a hasty glance at Ericsson's Caloric Engine, which excited so much interest a few years ago in England; and which, if it should be brought into practical operation, will prove the most important mechanical invention ever conceived by the human mind, and one that will confer greater benefits on civilized life than any that has ever preceded it. For the object of it is the production of mechanical power by the agency of heat, at an expenditure of fuel so exceedingly small, that man will have an almost unlimited mechanical force at his command, in regions where fuel may now be said hardly to exist. The announcement of such an idea may startle all those acquainted with the nature of heat, and the well known limits of the amount of mechanical power which any given quantity of caloric is capable of producing; more particularly, as it is a well established fact, that a given quantity of heat will exert an equal amount of mechanical power, to whatsoever medium it may be imparted.

Ericsson's theory of heat is altogether in opposition to the received notion, that the mechanical force produced will bear a direct known proportion to the quantity of caloric generated; and that the power exerted in our best constructed steam engines is nearly the measure of that effect.

The late professor Harvefeldt, of Sweden, one of the first mathematicians of the day, stated in a public lecture, not many years ago, that there is nothing in the

Digitized by Google

theory of heat which proves that a common spirit lamp may not be sufficient to drive an engine of a hundred horse power. It will readily be believed that the professor had but few hearers who did not smile at the suggestion; but among those few we may number Ericsson, who, from the earliest period of his mechanical labours, had been in the habit of regarding heat as an agent, which, whilst it exerts mechanical force, undergoes no change. This extraordinary fact Ericsson exemplifies by a simple but conclusive illustration; for the readier reception of which, by the audience, it will be well to introduce particular dimensions. Suppose the piston of an ordinary steam engine cylinder to be at the bottom, and suppose the force of the steam intended to be admitted into this cylinder under the piston to act with the force of 100,000 pounds, which is the force on a piston of fifty inches diameter, acted upon by steam of fifty pounds' pressure to the square inch. Suppose the cylinder to be ten feet long, and the piston to be loaded with a weight equal to these 100,000 pounds. If, now, a sufficient quantity of steam of the stated pressure be admitted from below the piston, this load will be elevated through the whole length of the cylinder; and hence we shall have raised a weight of 100,000 pounds through a space of ten feet. But who will contend that this immense amount of mechanical force has required any expenditure of heat? Does not the steam, after having lifted this weight, contain just as much heat as it did before leaving the steam boiler—less only the losses by radiation? And does not that heat retain all the properties after the operation which it possessed before? Am I, then, incorrect in stating that we have obtained this power without changing the nature, or diminishing the energy of the heat employed?

But although nature has furnished us with an agent of such extraordinary properties for the production of mechanical force, how imperfectly do we employ it! In the low-pressure engine, we turn the steam, after having performed its good office, into a condensing apparatus, where the heat is in a manner annihilated; and in the high-pressure engine, we throw it away into the atmosphere. Yet men, even of mechanical distinction, ridicule the idea of superseding the steam engine; and science seems to pause contentedly in the contemplation of its admitted perfection. For a mere theorist to attempt an exposition of its defects, or to suggest a substitute, would, under such circumstances, excite little attention; but the opinions and views, in this connexion, of a man of great practical knowledge, who has planned and constructed hundreds of steam engines, are entitled certainly to peculiar consideration.

From what I have already said, it will be readily inferred that the principle forming the basis of the Caloric Engine is that of returning the heat, at each stroke of the piston, and using it over and over again. This is obviously impracticable, if

Digitized by Google

steam is employed as the acting medium. Ericsson, therefore, uses the permanent gases, and, in preference to all others, atmospheric air. The object which he seeks to accomplish is simply this—that the heat, contained in the air which escapes from the working cylinder, should be effectually taken up by the air which enters it, at each stroke of the engine. This result Captain Ericsson has accomplished by means of an apparatus which he styles a regenerator; and so perfectly does it operate, that the heat employed in first setting the engine in motion continues to sustain it in full working force, with no other renewal or addition than may be requisite to supply the inconsiderable loss by radiation. This remarkable invention was first brought before the scientific world in London in the year 1833, though it had been a favourite subject of speculation and reflection with Captain Ericsson for many years. With the prominent exception of the celebrated Dr. Andrew Ure, and Professor Faraday, now the most distinguished chemists in England, nearly all the leading scientific men of the day united in condemning the principle on which it was based as unsound and untenable.

After such preliminary experiments as he deemed requisite to enable him to ascertain the best form of the regenerator, the inventor at once constructed in London a working engine of five horse power, the performance of which was witnessed by a great number of gentlemen of scientific pretensions in that metropolis. Among others, the popular author, Sir Richard Phillips, examined it; and, in his Dictionary of the Arts of Life and of Civilization, he thus notices the result of this experiment. "The author has," he says, "with inexpressible delight, seen the first model machine of five horse power at work. With a handful of fuel, applied to the very sensible medium of atmospheric air, and a most ingenious disposition of its differential powers, he beheld a resulting action in narrow compass, capable of extension to as great forces as ever can be wielded or used by man."

The interest which this subject excited did not escape the British government. But a short time was permitted to elapse before the Secretary of the Home Department, Lord Althorp, now Earl Spencer, made his appearance in the engine room where the new motive power was in operation. His lordship was accompanied by Mr. Brunel, the constructor of the Thames Tunnel, and a gentleman at one period distinguished for his skill and enterprise as an engineer. At this time he was somewhat advanced in years, and therefore, perhaps, not most judiciously selected by his lordship to judge of this invention. At the very outset he conceived an altogether erroneous notion of the nature of the new power, which he would not suffer to be corrected by explanations. An earnest discussion arose between Mr. Brunel and the inventor on the spot, which was followed by a protracted correspondence. The result

Digitized by Google

was, that an unfavourable impression of the new power was communicated to the British Government.

The invention fared but little better at the hands of Professor Faraday, from whose efficient advocacy and influence the most favourable results might have been anticipated. This gentleman had announced that he would deliver a lecture on the subject in London, in the spacious theatre of the Royal Institution. The novelty and interest of the invention, combined with the distinguished reputation of the lecturer, had attracted a very large audience, including many individuals of eminent scientific attainments. Just half an hour, however, before he was expected to enlighten this distinguished assembly, the celebrated lecturer discovered that he had mistaken the expansive principle which is the very life of the machine. Although he had spent many hours in studying the caloric engine in actual operation, and in testing its absolute force by repeated experiments, Professor Faraday was compelled to inform his hearers, at the very outset, that he did not know why the engine worked at all. He was obliged to confine himself, therefore, to the explanation of the regenerator, and the process by which the heat is continually returned to the cylinder, and re-employed in the production of force. To this part of the invention he rendered ample justice, and explained it in that felicitous style to which he is indebted for the reputation he deservedly enjoys, as the most agreeable and successful lecturer in England.

Other causes than the misconception of a Brunel and a Faraday operated to retard the practical success of this beautiful invention. The high temperature, which it was necessary to keep up in the circulating medium of the engine, and the consequent oxydation, soon destroyed the pistons, valves, and other working parts. These difficulties the inventor endeavoured to remedy, in an engine which he subsequently constructed of much larger powers, but without success. His failure in this respect, however, has not deterred him from prosecuting his invention. During his residence in this country, Captain Ericsson has constructed two engines, though purely experimental, with the view of working at a reduced temperature; and he is gradually, but surely, approaching the realization of his great scheme.

Our prescribed limits will not permit us to follow the deeply interesting analogies, traced by Ericsson, between the principle of the caloric engine, and that of animate and terrestrial force. Some of his views and calculations on the subject, however, I cannot omit to present to this audience—chiefly to meet the objections of those who imagine that they can detect in the caloric engine principles that involve the chimera of the perpetual motion.

The sophist accounts for the continued reproduction of the forces expended in nature, by what he calls a nice balance. If this expression fail to convey a distinct idea

Digitized by Google

to those who hear it, it is probably because no very distinct idea on the subject exists in the mind of him who employs it. He imagines that all force exerted in nature is productive of an equivalent counter-force; but how nature makes this counter-force subservient he cannot explain. Were his doctrine true, the principle of the caloric engine would very much resemble that of the perpetual motion; for its object is the production of a continued force, almost without reference to the amount of the original exciting cause. Surprising as this may appear, the truth of it is manifested by the principal operating forces in nature, nearly the whole of which, as Ericsson contends, in a strictly mechanical view, are wasted; or, in other words, are exerted without producing any useful or available counter-effect. And yet nature has ever at her command an unlimited amount of force!

To illustrate the amount of this force, I will present one or two calculations, by Ericsson, that may excite the astonishment of all who have not had their attention particularly directed to this subject. The quantity of water discharged at the Falls of Niagara is estimated at 28,000 tons a second; which is equal to 3,360,000,000 of pounds falling through a space of 150 feet in a minute, or of 504,000,000,000 through the space of one foot. If we divide this amount by 33,000, which is the number of pounds that a single horse is capable of moving through the space of one foot in a minute, the result shows the power of the Falls of Niagara to be equal to 15,000,000 of horse power constantly exerted. Now, an ordinary steam engine of one horse power, kept constantly at work for one year, consumes twenty tons of coal. To produce by means of steam power, therefore, a constant force, equal to that of the Falls of Niagara, would require the annual consumption of three hundred millions of tons of coal. But the Niagara forms only a small portion of the descent of the St. Lawrence; and the whole earth is watered by rivers and falls, the united force of which amounts to many hundred times that shown by our calculation. What a stupendous force is here exhibited! And yet no one can deny that it is, in a mechanical sense, entirely lost, and that nature reproduces it constantly by fresh means. It requires but a word of comment on this illustration, to exhibit the imperfection of the means employed by man for the production of mechanical power. By keeping up a force equivalent to a few millions of horse power in our steam engines, we are fast exhausting our mineral storehouses; while nature, in constantly exerting a force a million of times greater, causes no change anywhere that is perceptible to the most rigid scrutiny. Here, then, we have a caloric engine on a vast scale, and a regenerator that is susceptible of no improvement.

The forces to which I have hitherto alluded, many will ascribe to solar influence; a term by which they merely assign a remote location to the acting cause, but fail to

Digitized by Google

explain it. To meet this class of reasoners, Ericsson has prepared another calculation, based upon those forces in animate nature, for the production of which solar influence is not absolutely necessary. This calculation estimates the amount of force constantly exerted by animate nature, as equivalent to that of an engine of 100,000,000 of horse power. It is well ascertained that man is capable of exerting a force equal to raising fifty pounds through a space of one hundred feet, for every minute during eight hours out of the twenty-four. This force may not be always exerted, but it is within the ability of every man. Hence we shall underrate the average individual power, if we state it to be adequate to raising ten pounds constantly through a space of one hundred feet per minute; and, assuming the number of human beings to be 1,000,000,000, their united force will be equal to an engine of 30,000,000 of horse power.

We shall not much err in estimating the force which the quadrupeds are capable of exerting at the same amount; and the inhabitants of the sea are constantly exerting a far greater force. We know that the power of the whale, for instance, frequently exceeds twenty horse, so that the amount assumed would be made up by a million and a half of these creatures alone. It is obvious, then, that the united force of animate beings on our globe is much more than equivalent to an engine of 100,000,000 horse power. It has already been stated, that an engine of one horse power consumes twenty tons of coal a year. Hence it follows, that, with our present imperfect means of producing mechanical power, we should require two thousand millions of tons annually to exert a force equal to that of animate nature. To maintain that force, therefore, even on our underrated estimate, for a single century, a mere speck in time, would require two hundred thousand millions of tons; demanding the complete exhaustion of a coalfield of 3,000 square miles in extent, with a solid stratum of mineral one hundred feet in thickness. And yet animate nature perpetually maintains this force, without any perceptible permanent change.

True it is, we do not know on what mechanical principles it is maintained, nor can we explain the precise cause of animate force; but it would be irrational to attribute it to the arbitrary will of Omnipotence. We cannot but assume that it depends solely on the mechanical laws of nature; and in this view of it we are led, irresistibly, to the conclusion that there exists in nature a principle of absolute reproduction of mechanical force.

We need not assert, that this principle depends on the extraordinary properties of heat which we have been considering. It is enough for our purposes to have demonstrated that nature exerts an infinite amount of mechanical power, without causing any perceptible change. However imperfect may be the principle of

Digitized by Google

Ericsson's caloric engine, yet it resembles the sublime reproducing principle of nature, and if not defeated by practical obstacles, this invention will prove a greater boon than the ingenuity of individual man has ever before enabled him to bestow upon his race.

Mr. John Braithwaite has promised to procure the working drawings, showing scientifically Mr. Ericsson's principle, which we shall not fail in publishing in our Papers.

JOHN WEALE.

Digitized by Google

Digitized by Google

MONS. ARAGO'S REPORT

ON THE

ATMOSPHERIC RAILWAY SYSTEM,

AND ON

THE PROPOSED ATMOSPHERIC RAILWAY AT PARIS,

SEVEN MILES AND A HALF LONG.

MONS. ARAGO'S REPORT ON THE BILL PROPOSED TO OPEN A CREDIT FOR AN EXPERIMENT OF THE ATMOSPHERIC SYSTEM OF RAILWAY.

GENTLEMEN, we comply with the request which has been so generally expressed in the chamber by endeavouring to describe, in as few lines as possible, the different systems of atmospheric railways which are at present contending for public favour.

These remarks will, moreover, have the advantage of discriminating, in general terms, the striking peculiarities of these inventions from those gratuitously attributed, or which, to be admitted, would demand a rigid inquiry.

The atmosphere presses in all directions with the same intensity; it acts alike on a horizontal and vertical surface.

The atmospheric pressure, estimated perpendicularly to the plain surface, that alone of which we have to speak here, is measured in all places by the weight of a volume of mercury having the surface pressed as base, and for height that of the barometer.

At the level of the sea, the height of the barometer is seventy-six centimètres (thirty inches). If we recollect that, for equal volumes, mercury is thirteen and a half times heavier than water, we may conceive that the pressure of the atmosphere on a surface of any extent would become a forcible moving power, whenever we are able to annul the pressure in the opposite direction, arising from the same cause, and which generally balances it.

Let us now, for example, imagine on the surface of the ground, a tube, half a mètre diameter, (nineteen inches and three quarters,) open at both extremities, and in which there is a piston accurately adjusted, and capable of sliding in either direc-

Digitized by Google

tion. This tube has been called, according to the English term, "the propelling tube," under which name we shall also designate it.

The atmosphere impels the piston of the propelling tube, from right to left, with a very considerable force, easy to be calculated. An exactly equal force impels it from left to right; in this case, therefore, the piston will remain immoveable.

This being granted, let us close hermetically the tube at the left end, afterwards let us withdraw all the air contained between the closed end and the piston, by using for this purpose a system of pumps and valves similar to those so well known in philosophical lecture rooms, under the name of air-pump.

By withdrawing the air, we destroy the pressure acting on the piston from left to right, and which prevented it from yielding to the force exerted on the opposite side. After the operation spoken of, the latter force alone exists, and it cannot fail to drive the piston towards the left with considerable rapidity and power, as soon as we have removed the wedge or other similar obstacle which retains it in its place.

If, instead of withdrawing *all the air*, we only remove a *portion* in that part of the horizontal tube contained between the piston and the closed end on the left; if, for example, instead of reducing the atmospheric pressure in that portion of the tube to zero, we merely arrive at that of half its normal value, a force will remain acting on the piston from left to right, with an intensity equal to the half of that acting in the opposite direction, and the moving power of the piston will be ultimately reduced to the half of that which it would have been in the former example. A less perfect vacuum would reduce this propelling power to a third, fourth, fifth, &c.

It is to be understood that after the piston acts from right to left, it is sufficient, should we wish it to move in the opposite direction, to leave the tube on the left in free communication with the atmosphere, to close that on the right, and to produce a vacuum more or less perfect.

By attaching a package in any suitable manner behind the moveable piston, we shall have the system of transport for merchandize, letters, and papers, proposed by the Danish engineer, Mr. Medhurst, in 1810. On increasing considerably the dimensions of this tube, in such a manner that it may contain a train of carriages, we may then form an exact idea of the experiment attempted by Mr. Vallance, on the Brighton road, in 1823, in a temporary wooden tube of two mètres diameter, (about six feet, seven inches and one eighth.)

It is evident enough, without even taking it into consideration in an economical point of view that the public would never consent to be inclosed, according to Mr. Vallance's system, in an iron tube of indefinite length, that every one would feel a natural reluctance to travel in perfect darkness, however great the velocity. Thus,

Digitized by Google

Mr. Medhurst, wishing to improve on his first invention, endeavoured to transmit to the exterior such motive force as might have been communicated to the internal piston. To these experiments succeeded those of the American engineer, Mr. Pinkus, and then again those more successful of Messrs. Clegg and Samuda.

The first experiments of the two English engineers, made at Chaillot, in 1838, were followed by others less imperfect at Wormwood Scrubs, near London. At length, by a loan obtained from the English government of 625,000 francs, (£25,000,) Messrs. Clegg and Samuda were able to proceed to the construction of an *atmospheric railway* of 2,275 mètres long, (2,490 yards,) from Kingstown to Dalkey.

We shall now say a few words on the manner in which they have contrived to establish an immediate and unyielding connexion between the piston on which the atmosphere acts as a moving power, and the leading carriage of a train running outside the tube on the ordinary rails.

This inflexible connexion, of which we have just spoken, could not be established conveniently, except by means of a metal rod passing from the piston to the carriage. Now, as it is necessary that this connexion should be maintained during the entire course of the piston, there must be a longitudinal opening in the upper surface of the tube. It is along this upper slit, that the metal arm travels, by means of which the movement of the piston is communicated to the leading carriage of the train, and thence to all the others. This rod or arm has been very justly called the *connecting* or *moving arm or plate.*

But, it may be asked, if there is an opening in the tube, how is the vacuum to be produced? We give the reply.

The opening is continued the whole length of a valve, by which it is hermetically closed; the vacuum can be thus successively produced in that part of the tube to the left and right of the piston, as in the closed tube of which we have spoken in the commencement. By a movement, to which we shall presently refer, the valve is partially opened near the piston, so as to let the *connecting plate* pass; after which it immediately falls by its own weight.

This is the most delicate part of the apparatus. If the valve accurately closes the opening, a perfect vacuum is produced and maintained, by which we obtain a permanent and powerful moving force. On the contrary, should the valve allow the air to enter by any fissure, we cannot produce a sufficient vacuum but by having recourse to a very powerful air-pump, and, moreover, this imperfect vacuum can only be supported by the continued action of the pump. It is more especially in the mode of closing the longitudinal opening of the propelling tube, that the systems of Messrs. Samuda and M. Hallette differ from each other. The longitudinal valve of Messrs. Samuda, which closes the opening of the tube, is formed of a strip of leather, of

Digitized by Google

indefinite length, strengthened above and below by a series of iron plates of thirty centimètres long, (about one foot,) and not leaving a space between them of more than a centimètre, (about three-eighths of an inch.) Weight is thus given to the valve without destroying its elasticity. The leather is closely and hermetically fastened, by one of its edges, to one side of the opening. The other edge remains unattached and moveable, and, when the valve is closed, it merely rests on the second lip of the opening, which has been previously covered in its entire length by a composition of wax and tallow. When the valve opens, that edge of the leather fastened to the tube bends, and thus acts as a true hinge.

We can form a sufficiently accurate idea of the manner in which the strip or band valve of Messrs. Samuda is arranged and acts, by extending on a table a long selvage of cloth, then gently stretching, and afterwards gluing, it by one of its edges to the table. In passing the finger between the table and the cloth, along the unattached side of the selvage, a partial bending or rising of the cloth will take place wherever the finger may be placed. At a little distance this rising of the cloth does not occur, or is at least imperceptible.

Messrs. Samuda's valve is never raised to a perpendicular position; its movement never exceeds an angle of 45°. The opening is then sufficient to give passage to the moving plate, which is large and considerably bent, and unites the piston to the guiding carriage.

This plate, the necessity of which every one must see, is placed a little *behind* the piston, so that the air can never freely penetrate into that portion of the tube which the piston is about to enter. In reality, the rising of the valve is not directly caused by the action of the arm; this movement is produced by two rollers placed in the tube, *behind* the piston, and a little in front of the arm.

The mere falling of the valve by its own weight does not give it sufficient adherence to the edge of the opening, so as to prevent the entrance of air into the tube; therefore, it scarcely resumes its place before it is heavily pressed by a wheel fixed at the back of the leading carriage, to which also is attached a cylinder filled with burning charcoal, for the purpose of melting the composition of tallow and wax of which we have before spoken.

The principle of M. Hallette's longitudinal valve is quite different.

The propelling tube of our countryman, like that of Messrs. Samuda, has a longitudinal opening in its upper surface. The opening is placed throughout its whole length between two hollow semi-cylinders of metal with their concavities facing, forming part of the main tube, and cast together with it. In each of these longitudinal concavities, M. Hallette places a tube of thick and close-woven material, rendered impervious by the usual well known means; air is compressed into these tubes by fixed

Digitized by Google

engines, which, acting in another manner, produce the vacuum in the main propelling tube.

By their swelling externally, these hose exactly fill the metal semi-cylinders, and by a similar operation towards the centre of the tube, they are brought in contact, or, more properly speaking, press against each other in such a manner as to close the opening hermetically.

In the ingenious system of the talented Arras inventor, (M. Hallette,) it is not, as may be seen, on the *edge* of the longitudinal groove that the propelling tube is closed. The groove remains open and free, but the two swollen hose prevent the air from entering from above by their mutual contact, and laterally, because they rest very accurately on the interior surface of the two semi-cylindrical ears or continuous bosses, placed right and left of the groove.

We have here no valve for the connecting arm to lift. In moving, it enters between the two swollen hose and separates them for a moment. Neither is there a compressing wheel, nor a composition to be melted; the elasticity of the air injected into the hose is sufficient, and after the passing of the arm, this elasticity replaces every thing in its original position.

Before we proceed further, it may be well to remark, that the connecting arm at that part on a level with the two swollen hose in contact is of but trifling thickness; its form is that of a thin lens, having the edge in the direction of its movement, so that it is never necessary the hose should be at any time considerably separated, and they come suddenly in contact as soon as that narrow portion of the lenticular moving or connecting arm has passed.

These details will facilitate the labours of the committee.

At the first view, we may ask ourselves, if we can hope for future success from a system of locomotion into which enters, as principal agents, a strip of leather of immense length, a composition of wax and tallow, and a hot iron to dissolve the wax; or would it not be better to occupy ourselves in rendering more perfect the ordinary locomotive, rather than turn our exertions and expectations to those combinations which require, in the entire length of the propelling tube, that is, for a considerable number of leagues, that accurate and hermetical contact, which we can only produce with difficulty on the small air-pump in the lecture room?

The question would seem difficult, but experience has answered it.

It is nearly a year since the Dalkey line has been made, and more than two months since it has been opened for traffic, during all which time the longitudinal leather valve has acted satisfactorily. It is not in this respect that doubts have arisen in the minds of engineers, as to the economical advantages which such a railway might offer under certain given circumstances.

Digitized by Google

The possibility of acquiring great speed on the atmospheric railway cannot be an object of doubt to those who are aware with what rapidity air will rush into a vacuum. Nevertheless, it may not be superfluous to add here, that between Kingstown and Dalkey, with a propelling tube of only thirty-nine centimètres diameter, (about fifteen inches and a half,) a train of thirty tons has travelled at the rate of eighty-three kilomètres (fifty-two miles) an hour.

From the nearly total absence of danger, the atmospheric railway must be favourably received by those who still remember the dreadful accident of the 8th of May, 1842. Two trains cannot enter on the same tube so as to come in collision; the leading carriage, that immediately connected with the piston, cannot get off the rails, and for the most part, such an accident occurring to any of the other carriages would not be attended with serious consequences, as the wheels would merely plough up the earth on the side of the road.

Trains on the atmospheric railway, disencumbered of the heavy locomotive of the actual system, may be more easily stopped by the action of the break, and though the rails are lighter, their wear and tear will be much less; and in both respects, economy and safety will be found in the working.

Let us now state some of the points which the Dalkey railway leaves undetermined; and see what are the principal problems to which the proposed experiments may furnish a solution.

Fixed engines produce, by a few minutes' working, a certain motive power in the interior of the propelling tube. The power thus engendered, is continually becoming weaker; but to what extent in a given time? In this loss of power, what are the respective quantities of air entering by the longitudinal valve, and by the circular margin of the piston. On these points we have, at present, very loose estimates, rendering all accurate calculation impossible.

With respect to longitudinal valves, the Dalkey railway has half enlightened us only on that of Messrs. Samuda; M. Hallette's plan of closing has not been tried on it. In this respect, every thing has yet to be done. If the experiments at Arras succeed on a large scale; if the two artificial lips, to use the expression of our ingenious countryman, form an accurately hermetic closing; the atmospheric railway will then be presented to us under a new and extremely favourable light.

We must observe, also, that the experiments should not be alone directed to the pneumatic qualities of the two swollen hose[a]; we should also examine as to the durability of the leather facings which the inventor proposes to attach to the stuff of these

[a] It will be observed that the power of the elastic material to resist the expansion of the compressed air, and the other points, are the very points necessary as preliminaries to determine the practicability of the scheme.—Ed.

Digitized by Google

two hose, at least in the parts which come in contact with the moving arm; further, if the means suggested are sufficient to prevent the arm from getting heated in its rapid movement. Regarding it in these points of view, the problem would require the experiments to be performed on a considerable length of M. Hallette's tube.

We are ignorant of the extent of useful effect of fixed engines, which are intended to produce the vacuum, or at least a certain rarefaction of the air, in the propelling tube.

This is an essential point. So long as it remains undetermined, so long as we are without accurate information of the number of fixed engines necessary for the working of an atmospheric railway of a given length, the economical value of the different systems supplied by calculation, can neither be satisfactory nor demonstrative; it will be quite impossible to say with certainty what amount of traffic may render atmospheric locomotion preferable to all others.

The experiments at Dalkey have shown that fixed engines may be placed advantageously nearly two miles from each other; but we are perfectly ignorant what the result would be were they placed at three, four, or five miles. This is a question which requires solution, if we do not wish to pronounce inconsiderately on the advantages that may be expected from this new kind of road.

Notwithstanding the enlightened labours of such of our countrymen as have examined the Dalkey line, there still remains much for us to estimate on the friction of the leather packing of the piston on the layer of tallow with which the propelling tube is internally coated, and which, we may here observe, obviates the necessity of polishing or turning. In M. Hallette's tube we have also to estimate the friction of the moving arm on the leather covering of the two more or less swollen hose.

We may safely affirm, that these data, so necessary to an exact appreciation of the atmospheric system of propulsion, can nowhere be obtained with greater accuracy than when confided to the assiduity of our distinguished engineers.

Cases of interrupted connexion will frequently be met with in the propelling tube of a railway of some extent. The piston will then have to travel by its previously acquired speed, in the open air, from one tube to the other. We think it an evident exaggeration to compare this movement to running or tilting at the ring ("*jeu de bague*"): as experiments at Kingstown and Dalkey have fully proved that the transit spoken of is without difficulty. Still, this is a question to which in future experiments particular attention should be paid. Care should be taken to examine if the funnel-shaped form given to the ends of the adjoining tubes is such as to obviate all accidents.

The atmospheric railway furnishes us with the means of surmounting *all inclines.*

Digitized by Google

This is its most striking, and at the same time most valuable property. In this respect, no experiments are necessary. If required, calculation supplies, with rigorous exactness, the decreasing load which the same degree of vacuum can move on a horizontal surface, and on inclines of one, two, three, or five in a hundred. We should, on the contrary, carefully study the means of descending without danger all slopes, either by having recourse to the ordinary break, or what is far preferable, air breaks.

The system of M. Hallette in this respect offers us advantageous resources, since we can produce a considerable compression of air in the propelling tube, without a particle escaping, as the closing of the slit by the swollen hose or elastic tube remains equally impervious to the air by any pressure acting externally towards the interior, or vice versâ.

We have every necessary information in respect to atmospheric locomotion along a regular and nearly uniform inclination. It would be imprudent to speak with the same confidence where we have to contend with a visible and continued series of declivities and acclivities. The engineer can derive instruction from experience alone, as to the sudden changes of speed and other disadvantages which the laying out of a line under such conditions may present.

To what extent can we restrict curves in the atmospheric system? On the Dalkey line, there are certain parts, portions of circles of only 190 yards radius; here guard-rails are placed, and we have no information as to friction. This is a question of considerable importance, and it is to be desired that it were examined into, by uniting the atmospheric system with M. Arnoux's vertebrated waggon.

If the working piston were similar to that of the steam engine, if it entirely filled the propelling tube, if all its weight rested on the lower surface of the tube, we should have reason to anticipate those accidents which might be caused from the extreme speed of its movement; but the diameter of the central metallic part of the piston is visibly less than the propelling tube; it is, moreover, *suspended* to the moving arm, and by this again to the leading carriage of the train, so that the circumference of the piston and the interior circumference of the tube are perfectly concentric, but nowhere in contact; the annular space left between these two circumferences is filled by leather packing, arranged in a manner nearly similar to that which surrounds the piston of an hydraulic press. In the working of the piston, all the friction in the propelling tube acts on this leather washer. The leather must wear, and in effect does so rapidly. This is a point to which investigation should be directed in the experiments. The expense will at all times be trifling, but the facility of renewal would merit attention. Messrs. Samuda consider that the leather packing of their piston would require to be changed every 100 or 120 miles.

Digitized by Google

Even should it follow, after a rigid experimental comparison, that, on the principal lines, the ordinary locomotive ought still to be preferred to the atmospheric system of propulsion, at all events, the latter may be found to have advantages where, in ascending steep gradients, recourse is had to inclined planes, fixed engines, or ropes. This mode of application should be particularly pointed out to those engineers charged with the direction of the experiments. It will be necessary to examine carefully the means of combining both systems of transport for ascending, but more particularly for the descent of trains.

The Committee would be wanting in their duty, if they did not call attention to the atmospheric system of M. Pecqueur, as among those which would seem to merit a practical examination. Perhaps we may succeed in giving a general idea of this system, without being obliged to have recourse to a technical inquiry.

The ordinary locomotive is put in action by the vapour of water, worked at a pressure of four or five atmospheres. As the consumption of steam is considerable, this is supplied by a tubular boiler, of necessarily large volume, and that again by the water and coke from the tender.

Highly elastic air will produce the same effect in the locomotive engine as steam. From this arose the idea of substituting for the boiler an iron case, wherein, before leaving the station, air might be very forcibly compressed. This case, when nearly empty, would require to be replaced by others of compressed air at each succeeding station.

The idea was certainly very plausible. Nevertheless, hitherto it has not succeeded. Highly compressed air would be a source of danger from explosion. We must then have recourse to cases of considerable thickness, and, therefore, as to lightness, the advantages would not be as great as we might expect. We shall pass over other difficulties, which are also of some importance.

For these heavy and dangerous cases, which would certainly be a cause of delay at all the stations, M. Pecqueur has substituted an indefinite tube, placed on the ground between the rails, and in which he *compresses* air by means of fixed steam-engines, established from distance to distance along the line, as is necessary, to produce a vacuum in the atmospheric system on the Kingstown and Dalkey railway. M. Pecqueur's locomotive, which is supported by its wheels on the rails, as in the ordinary machine, draws all the supply of air which it requires for its working from the intermediate tube, in proportion as it travels. It is scarcely necessary to remark, that the compression of this air in the indefinite tube is very limited, merely to four or five atmospheres, if wishing to work at that degree of elasticity.

Digitized by Google

Such is the general system; but it is more particularly in the details that M. Pecqueur's machine is remarkable. Nothing can be more ingenious, better conceived, or more complete than the arrangements of the tubes and valves by which the machine supplies itself in working. In this respect, the whole mechanism is what we might have hoped for from the inventor.

The small railway which the Committee have seen, Rue Neuve-Popincourt, is sufficient to appreciate the different kind of valves which M. Pecqueur makes use of; but there are other matters which cannot be determined except by experiments on a large scale; as chief among these, we would place the effect of very great speed on the *key* with which M. Pecqueur opens his series of valves [a].

Gentlemen, in devoting but a trifling sum to the examination of this new system of propulsion, we run the chance of seeing, as that has but too often happened, a valuable and very ingenious French invention brought back to us by foreigners.

The Committee have readily participated in the opinions which have determined the Minister of Public Works to present the draft of the bill. But we think the proposed bill will be of little utility, if the experiments are not concluded, or considerably advanced, by the first month of the next meeting of the Chambers, otherwise it will be impossible to give information or gain a clear insight on the subject of laying out railways, which so important a report is sure to send forth.

The necessity of changing the present regulations, or, according to circumstances,

[a] In reading this part of the Report, we cannot but feel astonished at the importance which M. Arago would seem to attach to the system of M. Pecqueur. A system which, all our readers must see, is a mere modification of that long since rejected by Mr. Pinkus, and a description of which we have now before us, published in the "Railway Magazine," Vol. I. New Series, page 432, and signed, "Henry Pinkus, London, Nov. 22nd, 1836."

The difference between the two systems being, merely, that M. Pecqueur acts by *compression*, and Mr. Pinkus by *exhaustion;* both of which we cannot but regard as exceedingly unmechanical, by *loading* the rails unnecessarily with all the complicated machinery of a *locomotive;* forcibly calling to our recollection what we have very recently seen, incredible as it may appear, in the workshop of a station on the Belgium railway, a *steam engine working a steam engine.* If we are to hope for complete success in the atmospheric system, it certainly cannot be from such a mode of application. The public attention must, if we mistake not, be directed rather to the perfecting that of Messrs. Clegg and Samuda. Most of our English readers may be aware of the waste of time and talent, for nearly twenty years, (as the patent was obtained in 1827,) of the Messrs. R. and J. Stirling, of Scotland, in their attempts to substitute compressed and heated air for steam. Neither can we agree with M. Arago, in his recommendation of uniting the atmospheric system with M. Arnoux's vertebrated waggon, which a mere glance at the drawings would be sufficient to decide, in comparison with that of our ingenious countryman, Mr. Adams; where the former will be found exceedingly complicated, and that of Mr. Adams as much the contrary. J. T. F.

Digitized by Google

the system of locomotion, seems now to be generally acknowledged, at least in respect to economy; were it not for that, we might render it evident, by referring to some of the calculations of the proposed schemes for the Bordeaux and Strasbourg railways.

Gentlemen, let us make those experiments which may probably lead to a great diminution of expense, but let them be made quickly; the interests of France are involved in this.

The Chamber will understand from these observations, how the Committee, though resolved not to propose an amendment to the bill, have, in the course of these inquiries, examined where the proposed experiments might be made with the least *possible delay*, and under the most advantageous conditions.

The elevated plain of Satory, near Versailles, would not seem to us very favourable; two miles and a half only exceed by a third the length of the Dalkey line. In this locality, these new experiments would not even offer an advantageous repetition of those in Ireland, as from Kingstown to Dalkey, there are not, as at Satory, declivities nearly uniform; on the contrary, the line passes over a very difficult country, and the engineers have almost exactly followed the natural undulations.

In the environs of Saint-Cyr, moreover, there are proprietors to dispossess, and valuable time would be lost in the legal formalities of expropriation.

On the contrary, at the gates of Paris, we have land on the right bank of the Ourcq canal, which the managers of the canal will place to-morrow at the disposal of the government.

From the circular basin of Villette to Sevran, we have an interval of seven miles and a half, capable of being extended if necessary. In descending from the bank into the plain, and ascending again from the plain to the bank, engineers have the means of making their experiments on inclines of one, two, and even three in a hundred. At Bondy, we can descend four yards from the towing-path, and ascend again four yards to pass above the line of traffic. By ascending the bridge of Sevran, we shall rise seven yards nearly at once.

In short, by combining these declivities and acclivities with curves and counter-curves of small radius, we shall accumulate, in a limited space, more difficulties than any engineer can ever meet with in laying out a railway through the most uneven country.

The Minister of Public Works and M. Legrand have come before the Committee, and have again declared, that no locality had been definitively chosen for the performance of the proposed experiments. They seemed favourable to the elevated plain of Satory, as here the Chartres railway must necessarily pass; also, in case of com-

Digitized by Google

plete success, the atmospheric tube might remain in its position, and become the permanent means of ascending the steep inclines of a working railway; moreover, the mere idea is painful, that after placing, at a considerable expense, rails, propelling tubes, and steam engines, we should have to remove them when the experiments were finished.

The Committee, in appreciating the accuracy of the views and impressions of the minister, still consider that the experiments, in order to be instructive and conclusive, should present, in a restricted space, difficulties of gradients, and curves expressly sought, which the natural position of the country would probably allow us to avoid. The *experimental railway* would not, then, be found in that advantageous position which it would be possible to give a *working line*, and in general could not become permanent.

To the above, we have here an exception on the right bank of the Ourcq canal, if we wish to avoid a total demolition of a trial railway. The Commission has in effect received from the Paris Canal Company, an engagement expressed in the following terms: "If the experiments are made by the government on the canal bank, from the circular basin to Sevran, we engage to give £40,000 for the works and plant, which it may be possible for us to turn to some useful account in the service of the navigation and roads."

This proposition would seem to merit a serious enquiry. A reduction in the whole sum, of half the expense, is not to be disregarded. At the same time, considerations of economy are here but secondary; our principal object should be, to place, in the commencement of the next year, the Chamber and the entire country in such a position as to be able to form a clear and enlightened view on the atmospheric system of locomotion. In our opinion, the best situation is that which will allow the commencement and conclusion of the experiments with the least possible delay. It is in this respect the Committee have seen, with sincere satisfaction, that the minister has selected the bank of the Ourcq canal. Still, we would wish it to be understood, in thus expressing our desires, we should give way to the administration, if they can succeed, contrary to all probability, in finding a position in which the experiments might be carried forward under more favourable conditions, and more particularly, with *greater promptitude* than on the canal bank.

From the advantages pointed out in the preceding report, the Committee beg to offer to the consideration of the Chamber the adoption of the proposed bill.

J. T. F.

September, 1844.

Digitized by Google

THE GREAT IRON BRIDGE

ABOUT TO BE ERECTED OVER

THE RIVER NEVKA, ST. PETERSBURG.

THIS bridge has seven arches, and bids fair to be a most elegant structure. It is to be erected as a permanent one across the river, at the best end of the town, near the official residences of the court and government: a plan of the neighbourhood and its approaches is given. (See plate.) It will be seen that the navigation above bridge has been considered, as the opening seen in the plan and elevation will demonstrate.

SPAN OF ARCHES, which are seven in number.

	ft.	
2 side ones	107	each.
2 next ,,	125	,,
2 ,, ,,	143	,,
1 centre	156	,,

RISE OF ARCHES.

	ft.	
2 side ones	7.25	each.
2 next ,,	9.52	,,
2 ,, ,,	12.17	,,
1 centre	14.31	,,

Total width between centre and centre of outside ribs, 66 feet 8 inches.

The total estimated weight of the seven arches, exclusive of the roadway and railing, is :—

Tons.	
$6928\frac{9}{10}$	cast iron.
$342\frac{1}{10}$	wrought iron.

Digitized by Google

For the following short account of this bridge, we are indebted to the Liverpool Journal:—

"The fact of the Emperor of Russia having commissioned Messrs. Bury, Curtis, and Kennedy, the celebrated engineers of Liverpool, to construct an iron bridge to cross the Neva, at St. Petersburg, has caused considerable interest in the engineering world, and especially among the Russian, Prussian, and German officials now in this country. On Wednesday last, we visited Messrs. Bury's vast establishment at the Clarence Foundry, for the purpose of inspecting the progress of this gigantic and unprecedented undertaking; and the facts we were enabled to collect, through the courteous intelligence of the gentleman who showed us over the works, are pregnant with interest and singularity, not only as regards the construction of the bridge, but the general character and operations of the foundry, which, whether for extent, the number of hands employed, or the value of the produce of the labour, is equal to any engineering establishment in the world.

"The reader is aware that the Neva, in the most central and aristocratic part of St. Petersburg, is at present crossed by a bridge of boats, (the Pont d'Isaac,) over which there is a prodigious traffic, interrupted only at night time for the admission of ships through one compartment of the bridge, which can be easily shifted or removed for the purpose. In the spring, however, the huge masses of ice disengaged by the thaw drift down the current with such force, that it is necessary to let the bridge loose at one end and swing round at the other, so as to lie parallel with the quay; and even this precaution is occasionally unavailing against the ponderous impetuosity of the icebergs, which are sometimes (last year, for instance) propelled with such sudden violence against the boats, as to carry them away from their anchorage, and with them the whole of the superincumbent carriage and footway, into the Gulf of Finland, whence they are only rescued piecemeal by steamers. With a view to obviate occurrences of this nature, as well as also to carry out the imperial designs for beautifying and improving the Russian capital, the Emperor has resolved to erect a bridge of solid iron, on piers of Finland granite; and as he desires the execution of the work without the smallest possible delay, he has intrusted the castings to Messrs. Bury, who, when their new furnace, now in the course of being built, shall be completed, will be enabled to cast at the rate of no less than 150 tons a week; so that by the time the masonry is completed, the iron-work will be in a condition to be appended forthwith, thus perfecting this Titanic project in the course of about two years, when the bridge will be opened with a degree of *éclat* proportioned to the splendour and importance of the occasion.

"The structure will consist of seven arches. The span of the centre one will be

Digitized by Google

156 feet, and of the three arches on either side 143 feet, 125 feet, and 107 feet respectively. Another arch will be devoted to a species of swivel bridge, 70 feet wide, for the admission of ships to and from the Custom House. The buttresses of the piers will present to the current a sharp inclined plane, so that a descending iceberg will run up upon them, and fall to pieces from its own gravity. The bridge will be very flat, there being a fall of only seven feet from the top of the centre arch to the end of the last arch on either side. The average depth of water in the Neva here, throughout the year, is about 30 feet; and as the river is a tideless one, there is little variation, except when the wind sets strongly up from towards the Gulf, when the waters rise considerably, in some instances doing irreparable damage; as in 1824, when nearly 8,000 persons perished; and it is a current belief in Moscow, and all the inland towns, that one day or other will be realized the old Moujick prediction, that the phantom architecture of the new capital will be buried in the salt marsh out of which the genius of the first Peter raised it.

"As the shores of the Neva, on either side, are extremely low, the height of the crown of the centre arch from the water's edge will be only 21 feet—the spring of the arch but six feet. The extreme length of the bridge, from one abutment to the other, will be no less than 1,078 feet. The weight of iron alone will be nearly 8,000 tons, independent of the lamps and superb balustrades with which it is the emperor's intention to adorn it, and which together will probably weigh from 1,000 to 2,000 tons more.

"It is impossible, of course, that we can form any idea of the cost of this great undertaking; but it is probably within the mark to say that the price of the iron part of it will exceed £100,000—much of the labour to be bestowed upon it being of a very expensive character, several machines having to be constructed expressly for the preparation of various portions of the work. The segments of the arches have to be planned with the nicest precision where they join with the corresponding segments—there being 11 such in the centre arch alone; and as the castings will have to be on the very largest scale, and as every thing connected with the operation will necessarily have to be characterized by the utmost strength and solidity of material, and the best possible workmanship, all the details will of course be attended with heavy expenditure.

"It is almost needless to say that this is the largest order of the kind ever received in this country from a foreign one, as the bridge itself will be the most stupendous in the world, far exceeding Southwark Bridge in every thing but the cost. Indeed, the magnitude of the Neva Bridge can only be rightly computed by the casual reader contrasting its dimensions with similar structures at home, on which we have been accustomed to pride ourselves. Southwark Bridge—deservedly a

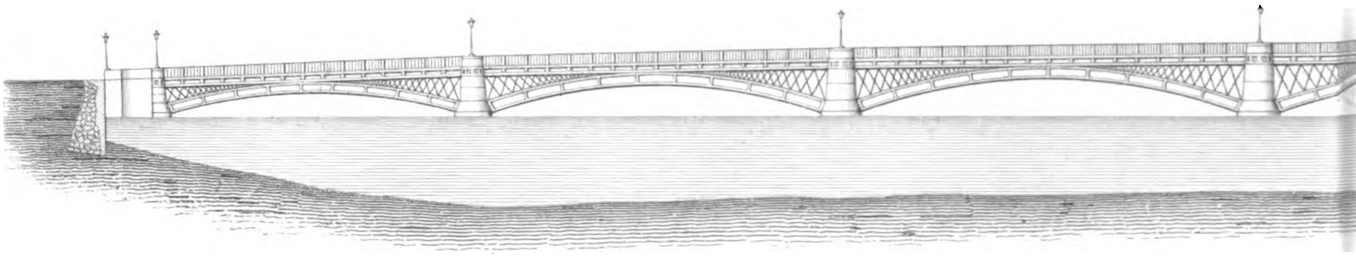
Digitized by Google

wonder in its way—measures but 708 feet from one abutment to the other, and the weight of iron is under 5,400 tons; whereas the length of the Neva Bridge, as just stated, is upwards of 1,000 feet, and the weight of iron will probably be little short of 10,000 tons. The spans of the three arches of Southwark are certainly much greater than those of the seven arches of the Neva Bridge—the centre one being 240 feet, exceeding the famous Sunderland Bridge by four feet, and the Rialto at Venice by 167 feet, or eleven feet more than the span of the Neva Bridge's centre arch; but in all the other attributes of grandeur and imposing effect, the Neva Bridge will much exceed even Waterloo Bridge, for while the width of the carriage-road or causeway of the latter is only twenty-eight feet, that of the Neva will be fifty feet; and while the parapet or foot-walk on Waterloo is only seven feet, that of the Neva will be ten feet wide. The weight of iron employed in this bridge will exceed by nearly fivefold that consumed in the erection of the Menai Bridge. Altogether, the Neva Bridge will be a most surprising evidence of what the skill and enterprise of a private British firm are able to accomplish; and that such an undertaking should have devolved on a Liverpool house constitutes an epoch in the commercial progress of the locality. There being three boat bridges on the Neva, it is highly probable that they will be replaced by iron ones, when the one we now speak of shall have come into use.

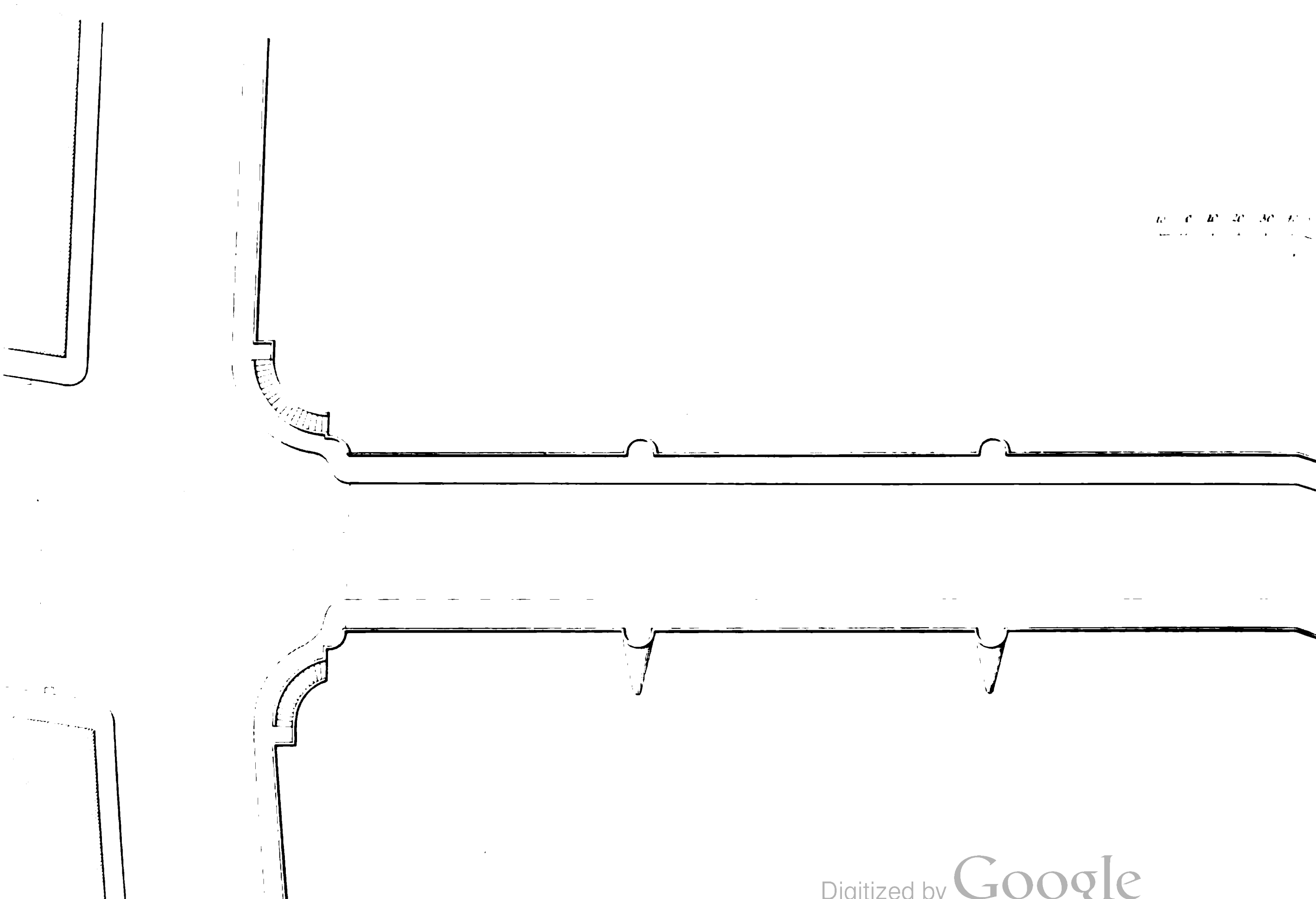
"Any facts appertaining to an establishment capable of executing an order of such amazing extent as this, cannot but be interesting to the Liverpool public. Messrs. Bury, Curtis, and Kennedy, as artificers in iron, as machine and engine and boiler makers, are equal to any in England, and, consequently, in the world. The foundry, with its multitudinous forges, casting rooms, and apartments of all sorts, which are united in one continuous succession, covers an area of nearly two acres and a half. We have heard that there have been made on the premises upwards of 200 locomotive engines, and marine engines approaching nearly 5000 horse power. The number of hands constantly employed, is probably not short of 900. The castings executed here are some of the largest ever attempted; many being, we should imagine, as high as thirty tons in a single piece. The whole of the buildings that might be supposed to be in the least danger from ignition are fire-proof, and were so at the period of their erection, fifteen or sixteen years ago, though it is generally believed that the principle now so universally being adopted in the new warehouses, namely, iron pillars and beams, arched brick floors, and party walls, is quite a modern introduction. We learn that Messrs. Bury are casting at the rate of nearly fifty tons a week for the erection of the new warehouses—a pretty conclusive proof of commercial activity, and of the recognition of a means for the prevention of those calamities which at one time gave so unenviable a notoriety to Liverpool."

Digitized by Google

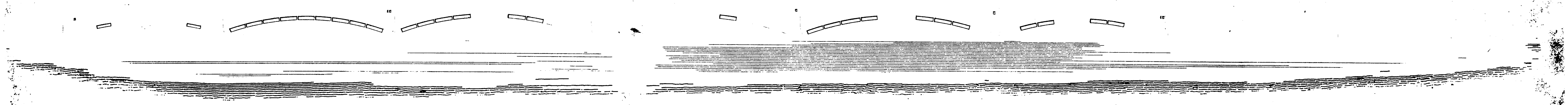
Digitized by Google



IRON BRI



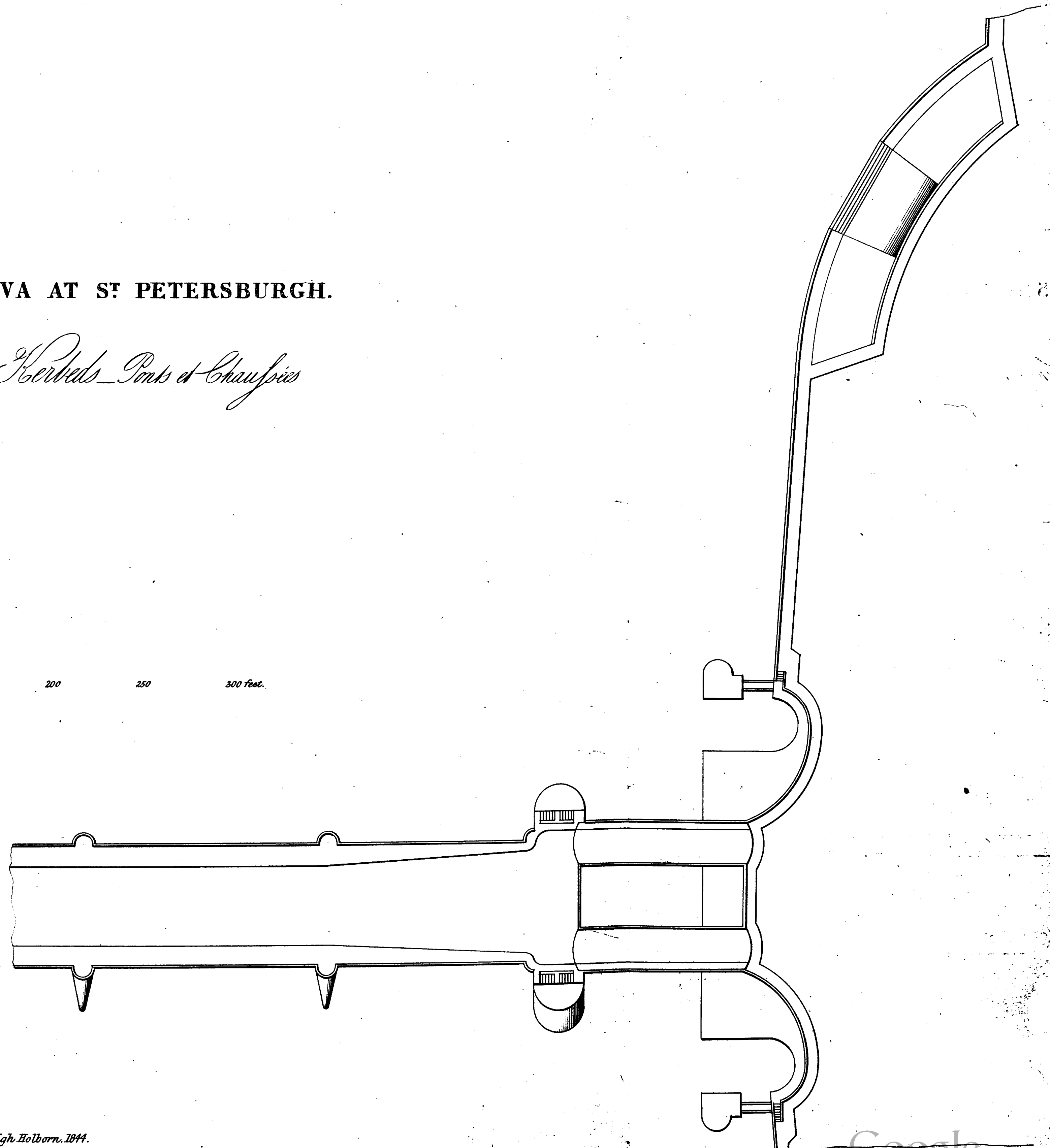
Digitized by Google



IRON BRID OVER THE NEVA AT S^{T} PETERSBURGH.

C ed by Colonel Kerbeds_ Ponts et Chaussées

10 0 10 20 30 40 100 150 200 250 300 feet.



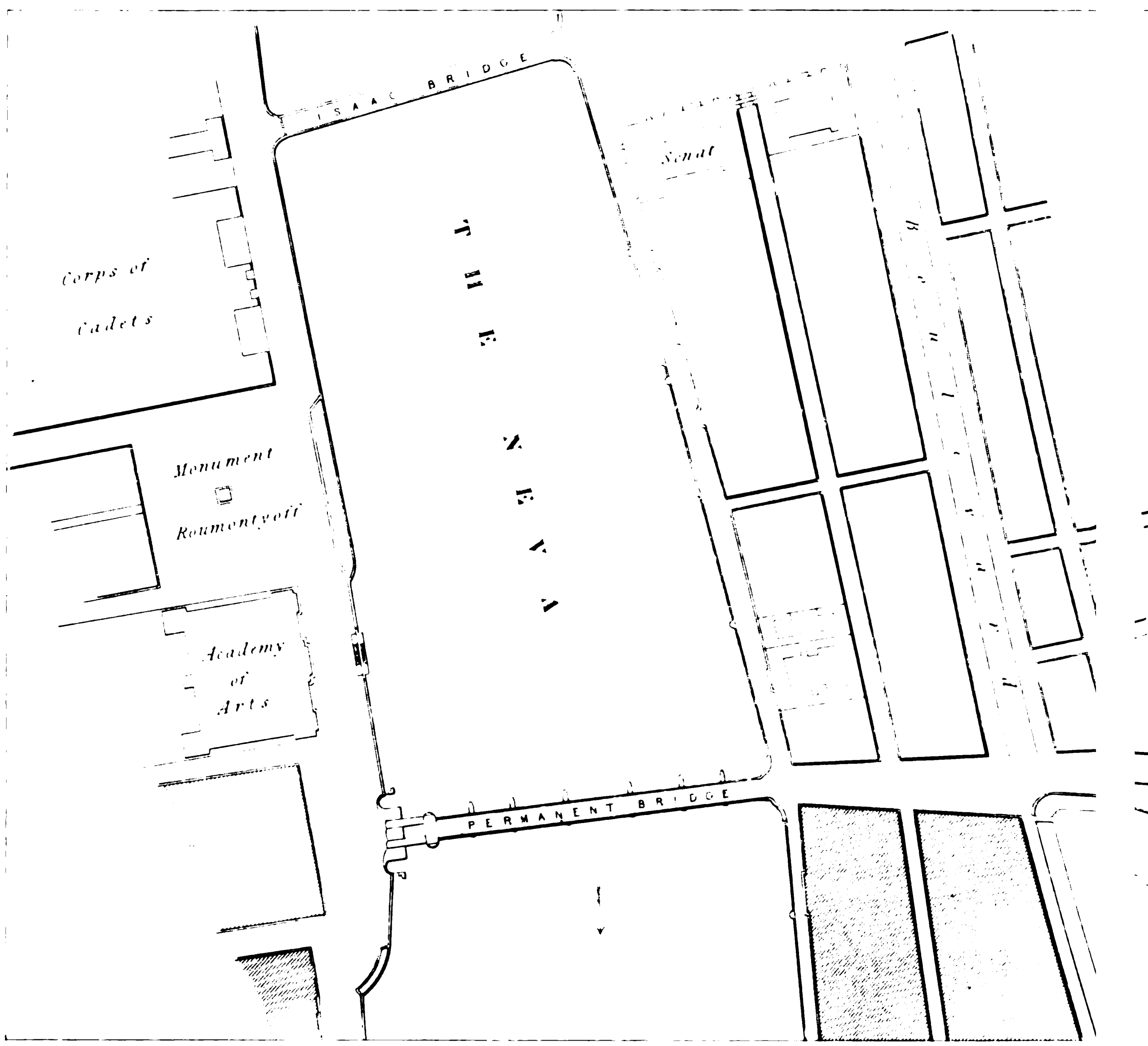
London. Published by John Weale, 59, High Holborn, 1844.

J.W. Lowry sc.

Digitized by Google

Digitized by Google

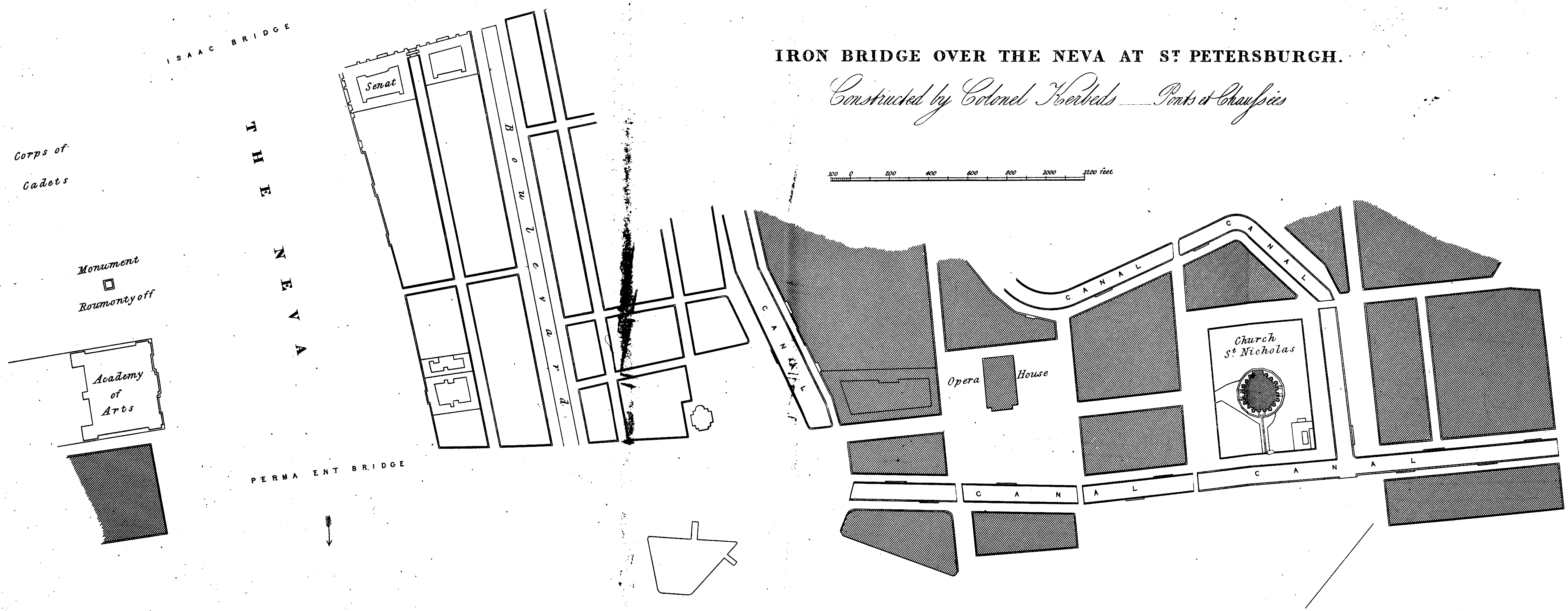
Digitized by Google



Digitized by Google

IRON BRIDGE OVER THE NEVA AT St PETERSBURGH.

Constructed by Colonel Kerbedz —— Ponts et Chaussées



London, Published by John Weale, 59, High Holborn, 1844.

Digitized by Google

A M

CONTAINING A

O

IT is quite u
means of ra
country; si
even from t
between the
most perfect
whole of Gr
and the con

There ar
sight insurm
being forme
gineer's skil
frequent in
depth, rapid
interference
of crossing,
in such situa
is at once ap
have soon s

* As the tu
under the Euph

Digitized by Google

A MEMOIR OF THE THAMES TUNNEL.

BY HENRY LAW.

SECTION I.

CONTAINING AN ACCOUNT OF THE DRIFTWAY ATTEMPTED AT LIMEHOUSE IN 1808; THE ORIGIN OF THE PRESENT TUNNEL; AND A DESCRIPTION OF THE OPERATION OF SINKING THE ROTHERHITHE SHAFT.

It is quite unnecessary to insist, in this place, on the importance and utility of the means of rapid and uninterrupted communication between all the internal parts of a country; since the truth of this proposition seems to have been universally admitted, even from the time of the Romans—whose first care was to construct good roads between their military stations—down to our own time, in which railways (the most perfect means of communication yet devised) are rapidly spreading over the whole of Great Britain; and not only over our own country, but likewise America and the continent of Europe.

There are, however, many localities in which nature has thrown great, and at first sight insurmountable, obstacles in the way of an uninterrupted and permanent passage being formed; and it is on these occasions that many of the finest proofs of the engineer's skill have been exhibited. Amongst these natural obstacles, none are more frequent in their occurrence than rivers, or arms of the sea, where, from the great depth, rapidity of the stream, or loose and shifting nature of the bed, or perhaps, the interference which would be caused to trade or navigation, any of the ordinary means of crossing, such as bridges or ferries, could not with convenience be applied. It is in such situations as these that the utility of a tunnel or subaqueous communication is at once apparent; and the idea of overcoming the difficulty in this way, appears to have soon suggested itself[a]; but all the early attempts which were made to form

[a] As the tunnel mentioned by Diodorus Siculus, as having been constructed A.M. 2006, by Semiramis, under the Euphrates, at Babylon, has been quoted as an instance of a subaqueous tunnel having been success-

Digitized by Google

tunnels in such situations were unsuccessful, and the difficulty of forming the tunnel was found quite equal to that which it was intended to remove.

The river Thames, flowing as it does through the centre of the great metropolis of the world, affords an immediate illustration of the foregoing remarks. The number and size of the vessels which frequent it, and crowd to the port of London, render the preservation of its navigation free and uninterrupted, an object of paramount importance, to which every other consideration must give place; at the same time, from the extensive commercial establishments on both sides of the river, some more convenient and certain means of passing across than that afforded by the ferries, becomes an important desideratum; especially a shorter means of transit for carriages and carts than that over London Bridge, with the necessity of passing through the narrow and crowded streets of Southwark and Wapping.

A bridge has more than once been proposed in the neighbourhood of Rotherhithe; but the first fixed bridge must necessarily terminate the limits of the port, and a bridge so constructed as to admit of the passage of moderately sized vessels, however well it might be contrived, would cause a great delay to the trade, entail a heavy expense in its efficient attendance, and at the same time, would afford but a very imperfect means of communication between the two shores.

With the view of removing this inconvenience, a subaqueous tunnel was proposed by an engineer of the name of Dodd, in 1798, for the purpose of connecting Graves-

fully accomplished by the ancients, we have thought it proper to extract from that historian the following account of this work, from which it will be seen, that if it was ever executed, (of which, from the exaggerated nature of the details, there may very reasonably be strong doubts entertained,) it did not even amount to a tunnel at all, but was nothing more than an arched passage, built in a large trench or ditch, excavated across the bed of what *had been* a river:—" After all these, in a low ground in Babylon [1], she sunk a place for a pond, four-square, every square being three hundred furlongs [2] in length, lined with brick and cemented with brimstone; and the whole five and thirty feet in depth. Into this, having first turned the river, she then made a passage in nature of a vault, from one palace to another, whose arches were built of firm and strong bricks, and plastered all over on both sides with bitumen four cubits [3] thick. The walls of this vault were twenty bricks in thickness, and twelve feet high, beside and above the arches; and the breadth was fifteen feet. This piece of work being finished in two hundred and sixty days, the river was turned into its ancient channel again, so that, the river flowing over the whole work, Semiramis could go from one palace to the other without passing over the river. She made, likewise, two brazen gates, at either end of the vault, which continued to the time of the Persian empire."

[1] Meaning, doubtless, the province of Babylon, the word being used in that sense in several other parts of the same book.

[2] Almost forty miles.

[3] About seven feet three inches.

Digitized by Google

end with Tilbury; this tunnel was to have been circular, and of sufficient capacity, (namely, sixteen feet internal diameter,) to admit of carriages passing. But the difficulties met with in the preparatory operation of sinking the shaft were so great, that the whole capital was expended without even effecting this; and in consequence of these unexpected obstacles, the attempt was discontinued.

As the trade, however, of the port increased, and became extended to both banks of the river, the want of a tunnel or bridge became more urgent; the Victualling Office and Naval Arsenals of Deptford and Woolwich, together with the extensive docks, the numerous manufactories, ship builders, coast wharfingers, and other traders on both banks, rendered a land communication eastwards of London Bridge not only highly desirable, but almost necessary; and notwithstanding the failure of the former attempt at Gravesend, a miner of the name of Vazie (who, from his skill and enterprize in mining operations, had been termed "the Mole,") having suggested the formation of a tunnel across the Thames at Limehouse, the idea was taken up by a number of enterprizing individuals, and a company was formed about the year 1805, under the name of the Thames Archway Company, and incorporated by an Act of Parliament, for the ostensible object of forming an archway under the river of sufficient capacity to allow of carriages passing.

Previously, however, to commencing the large tunnel, it was proposed by Mr. Vazie to sink a shaft at some distance from the side of the river, and thence to drive a small heading or driftway across under its bed, for the purpose of exploring the ground, and also to serve as an adit or drain while the more difficult and important work—the tunnel itself, should be in progress. Accordingly operations were commenced in the year 1805, by constructing a brick shaft only thirteen feet external diameter; but although upwards of 300 feet from the side of the river, the difficulties experienced in sinking it through a bed of gravel, full of water, and then through a quicksand, were so great, that when it had reached a depth of only thirty-five feet, it was determined to suspend the operation; and had it not been for the enterprize of one of the proprietors, who offered to complete this part of the undertaking at his own expense, it is most probable that nothing further would have been done towards carrying out the work. The shaft having been recommenced on a reduced diameter of ten feet, after much trouble, was carried to a depth of sixty-eight feet below Trinity High Water, at which depth it was determined to commence the driftway.

As the well constructing the driftway was considered to be a matter of the highest importance in the future progress of the works, and to involve the ultimate success of the undertaking, the directors passed a resolution "To suspend the works relating

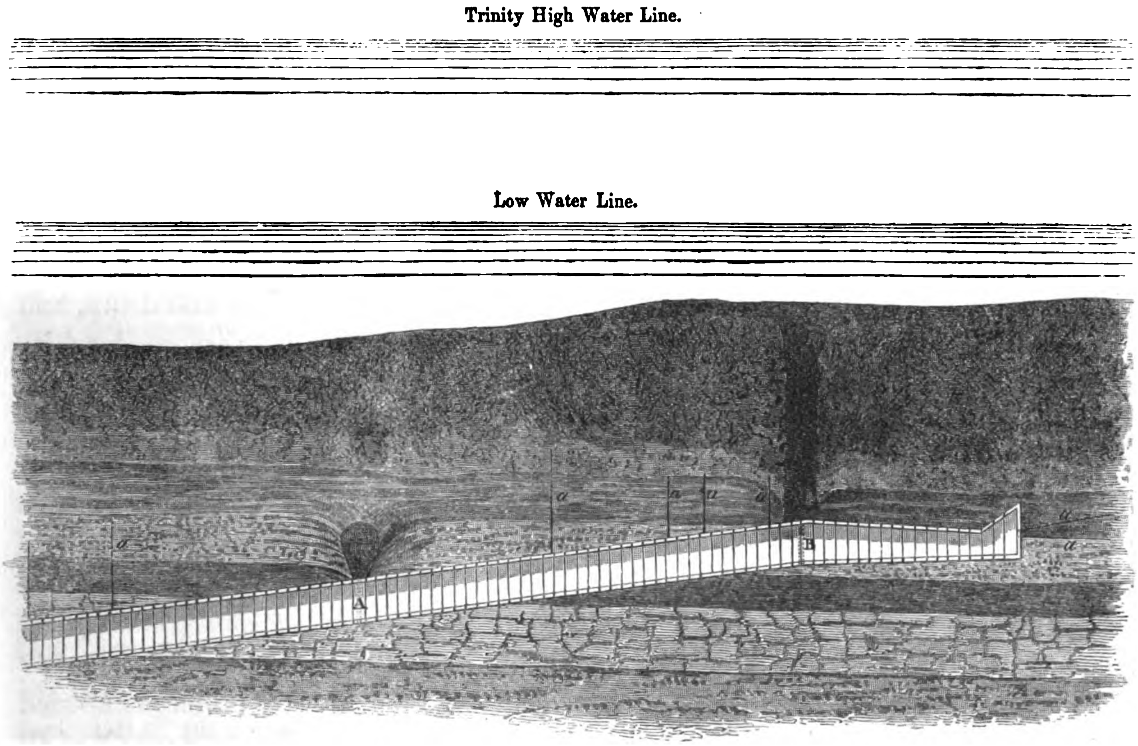
Digitized by Google

to the driftway until the opinion of a professional man of eminence had been taken on the various matters respecting it." Mr. Rennie and Mr. Chapman were in consequence consulted on the subject; but as these gentlemen did not coincide in their ideas, and could not afford the directors all the information which they required, they ultimately agreed to engage Mr. Trevithick, (a gentleman whose name was already connected with some of the most important mining enterprizes in the country,) to assist Mr. Vazie in superintending and directing the execution of the driftway.

Before commencing operations, it was agreed by both engineers to reduce the size of the drift to five feet in height, three feet in breadth at the bottom, and two feet six inches at the top. The driftway was accordingly commenced on these dimensions on the 17th of August, 1807, in a bed of dry green sand, at a very gentle ascent, that any water met with in the course of the excavation might run back to the shaft, and not inconvenience the miner in the face of the work. The works proceeded steadily forward, notwithstanding various slight obstructions which were met with in their progress. On the 5th of September, the engineers, in a joint report to the directors, strongly rcommended the immediate purchase of a thirty horse steam-engine, which was accordingly obtained. By the 19th of October, the driftway had been completed to the extent of 394 feet; at this period, owing to some misunderstanding arising between the directors and Mr. Vazie, the latter was removed from his office of resident engineer, and the sole direction of the driftway intrusted to Mr. Trevithick, to whom they agreed to give £1,000, provided he succeeded in reaching the opposite shore.

The works now proceeded without embarrassment, and at considerably less cost, the ground continuing nearly the same. When they had completed 559 feet, the driftway was turned to the west for twenty-three feet, and then continued in the same direction as before, for the purpose of exploring the ground in the northern part of the line of the proposed tunnel. The ground continued nearly the same, and the driftway progressed at a rate of about eleven feet two inches a day, until it extended 814 feet from the shaft; at this point it entered a bed of calcareous rock, the greater part of which was so hard, as to require the assistance of chisels and wedges to break it up. At a distance of 922 feet, the drift was made to incline upwards, at a rate of one foot in nine; the head of the driftway soon after entered a bed of sandy clay mixed with oyster and other shells containing some water, and the engineer discovered that the strata dipped to the northward, at a rate of about one foot in fifty. On the 22nd of December they had reached the position shown at A, in the accompanying sketch, and the head of the drift had entered two feet into this stratum, when, notwithstanding the workmen were proceeding with the utmost caution, the ground broke

Digitized by Google



in through a hole only six inches by thirty in the roof of the driftway, and a quantity of loose earth and water flowed in, leaving a hole large enough for a man to stand in, thereby discovering a quicksand about three feet thick, and four or five feet above the top of the drift. After considerable difficulty, the engineer succeeded in filling up and securing the cavity, and the work was once more resumed.

In order to draw off the water from this bed of sand, borings were made in the roof of the drift, and pipes *a a a*, driven up into the quicksand, through which a considerable quantity of water came. By these means, and by using the utmost caution, the driftway was extended seventy feet further, and reached the position shewn at B; but on the 26th of January, 1808, the ground once more broke in, and the sand and water made their way into the drift with such impetuosity, that in less than a quarter of an hour, the water reached nearly to the top of the shaft, Mr. Trevithick and one of the workmen having a very narrow escape.

Upon examining the bed of the river, an opening or hole was found, about four feet in diameter, and nine feet deep, and its sides nearly perpendicular. Notwithstanding the serious nature of this accident, the engineer succeeded in filling the opening, by means of clay in bags and other materials thrown into the river. The

Digitized by Google

water having been pumped out, the miners once more entered the drift, and it was determined to reduce its height to three feet, in the hope of being able by that means to pass through the dangerous ground. In this way the miners succeeded in extending the driftway twenty feet further through the quicksand, working all the while with the utmost intrepidity, on their hands and knees, although they were frequently driven back by the impetuous bursts of sand and water.

At this period the engineer reported, "that he had examined the bed of the river, and found the hole [at B] considerably increased both in width and depth, and the earth (at A, the place where the ground had first broken in) very much sunk; and that he had no doubt these two fractures communicated underneath. He then gave it as *his opinion* that an *under ground* tunnel could not be made in that line, unless the fractures were covered with caissoons, without which the further progress of the drift would be useless; but that he had no doubt of being able to make a tunnel over the *same* line through the river, sufficiently deep, into its bed, by means of moveable caissoons, or cofferdams, and at a less expense considerably than the original estimate for the underground plan, and *without any impediment to the navigation of the river.* Under these circumstances the further progress of the works was suspended."[a]

The Directors of the Company, however, being resolved to leave no means untried by which they might possibly effect their object, published a detailed "account" of all the difficulties which they had encountered, with a minute description of the ground, accompanied by an advertisement, offering a premium of £300 to any person who would furnish a plan, by means of which a subaqueous communication could be effected. In consequence of this advertisement fifty-three plans were received by the Directors, who appointed Dr. Hutton and Mr. Jessop to report upon them; the substance of their opinion is comprised in the following extract from the report of the latter of these gentlemen, who was well known as an engineer of considerable ability and experience:

"From the minutes of our examination of the numerous projects which have been laid before us, the Directors will understand that none have appeared to us to be unobjectionable; among the few, which from their ingenuity are recommended to particular attention, some which might be practicable, we apprehend, must be rejected, either from their *too great depth or length, which must be an insuperable objection* as to their utility; others from the very great expense, which must preclude any expectation of reasonable emolument to the adventurers, and all of them from the great degree of hazard which is inseparable from an undertaking so unlike any that has been heretofore accomplished.

[a] "Account" published by the Archway Company, March 30th, 1809.

Digitized by Google

"All these objections will, in our opinion, apply most particularly to those which are proposed as underground tunnels, and though *we cannot presume to set limits to the ingenuity of other men*, we must confess that, under the circumstances which have been so clearly represented to us, we consider that an underground tunnel, which would be useful to the public and beneficial to the adventurers, is impracticable."

In consequence of the unfavourable nature of this report, the works appear to have been discontinued, and so completely have they been destroyed, that no trace of the driftway now exists.

The ill success which had attended these two attempts, but more particularly the last one, which had been conducted with so much talent and energy, left an unfavourable opinion on the public mind as to the practicability of forming a tunnel at all; which feeling was still further increased by the reports of Messrs. Trevithick, Hutton, and Jessop, and the adverse opinion expressed by several eminent miners and scientific men of the day; so that the idea of really forming a communication between the two opposite shores of the Thames by a tunnel under its bed, was looked upon as quite chimerical.

It was in the year 1823, and under these disadvantageous circumstances, that the new plan of tunnelling invented by Sir Isambart Brunel, was first brought before the public, and proposals made for forming a tunnel on this plan from Rotherhithe to Wapping. The high opinion, however, which had been expressed by the Duke of Wellington, Dr. Wollaston, and other eminent scientific men, in favour of the plan, combined with the high character and well known ability of the engineer, caused the scheme to be regarded with more confidence by the public, and very little difficulty was experienced in forming a company, and obtaining subscribers.

The manner in which Sir Isambart's attention was first, we may say accidentally, directed to this subject is extremely interesting; it was in the year 1814, and while superintending some extensive works, which were in course of erection at the dockyard at Chatham, where he had just completed a small underground passage, (for the conveyance of timber from the Medway to the back part of the yard,) that he observed, lying in the dockyard, a portion of the old keel of a vessel, which had been much perforated by a sea-worm, termed the "teredo navalis,"[a] and which, having

[a] The teredo is an animal of so very interesting a nature, that we have subjoined the following short account of its structure and habits.

The teredo, although belonging to the class of worms, has a more perfect anatomical structure than many other worms, having more perfect respiratory organs, and a portion of red blood. Of this genus there are four or five varieties, but that best known, and which is alluded to above, is the *teredo navalis*, which seldom ex-

Digitized by Google

been sawn longitudinally, afforded a fine view of the perforations which these animals had made; his first observation was merely casual, and he passed on, but having arrived at his own small passage or driftway, the thought occurred to him that these worms had made diminutive tunnels; he immediately returned to the spot, and carefully examining what he now regarded with the greatest interest, he observed that the head of the worm was in the form of an auger, by means of which it slowly bored its way through the wood, being very cautious not to approach too near to the water, and leaving as it advanced a secretion behind it, which, slowly hardening, formed an impervious lining to its tunnel.

Improving on the first idea, Sir Isambart inquired whether a similar principle of operation might not be extended to, and practically made use of, in the construction of tunnels on a large scale. He shortly afterwards made a design for forming a subaqueous tunnel of a circular form, by means of an immense iron "worm," having an

ceeds eight or nine inches in length, and half an inch in diameter; there is, however, another variety, the *teredo gigantea*, of which a specimen is mentioned by Mr. Griffiths in the Phil. Trans., brought from Sumatra, which measured five feet four inches in length, and three inches in diameter, at the largest part.

The *teredo navalis* takes its name from living in timber which is constantly immersed in salt or brackish water, in which it bores a canal or tunnel, the interior of which it afterwards lines with a calcareous secretion, probably for the purpose of preventing the woody fibre from rotting, and falling in upon them. The body of the worm is of a soft nature, and so transparent as to allow of the action of the heart and respiratory organs being distinctly discerned. The head is enclosed between two triangular boring shells, which are concave, and the edges of which are toothed and jagged, for the purpose of filing away the wood; they are united together, and to the back part of the head, by a very strong muscle. From the middle of the exposed part of the head a proboscis projects, by means of which the animal fixes itself to the wood; and which acting as a kind of centre-bit, upon which the teredo turns from side to side, the wood is slowly rasped away by the file-like edges of the boring shells. The teredo commonly bores through the wood longitudinally, although they sometimes work across the grain, for the purpose of avoiding one another.

Fig. 1

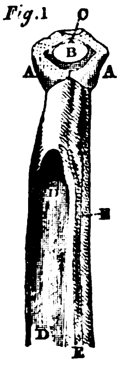


Fig. 2

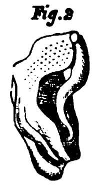


Figure 1, is a view of the head, and a portion of the body, of a specimen of the *teredo navalis* brought from Sheerness, drawn to the natural size. A A, are the boring shells; B, the proboscis; C, the mouth; D D, the contents of the abdomen seen through the transparent covering, and E, the breathing organs seen in the same way. Figure 2, is a side view of one of the boring shells of the same teredo, showing its cutting edge.

The destruction which these animals cause to the exposed parts of vessels, and in fact all timber which is constantly immersed in sea water, is so great that they were termed by Linnæus "Calamitas Navium;" and it is stated that in the year 1730, Holland was nearly inundated, from the sea dikes giving way in several places, the piles composing them having been so completely destroyed by the teredoes, that scarcely a piece of sound timber remained. Those who desire a further account of the teredo, may consult two papers in the Phil. Trans. for 1806, by Mr. Home, and Mr. Griffiths, and also a very curious old work by Sellius, entitled "Historia Naturalis Teredinis seu Xylophagi Marini," 1753.

Digitized by Google

auger head, and which was to bore its way through the ground by being slowly turned round, cast-iron segments being inserted behind it, as it advanced, which were to have been afterwards lined with brickwork, until the wall was of the requisite strength.

As to this trivial circumstance the present tunnel entirely owes its existence, this first design of Sir Isambart's, in its embryo state, can hardly fail to be of interest: we have, therefore, subjoined a sketch, taken from a drawing made at the time, showing the construction of this machine.

Fig. 1.

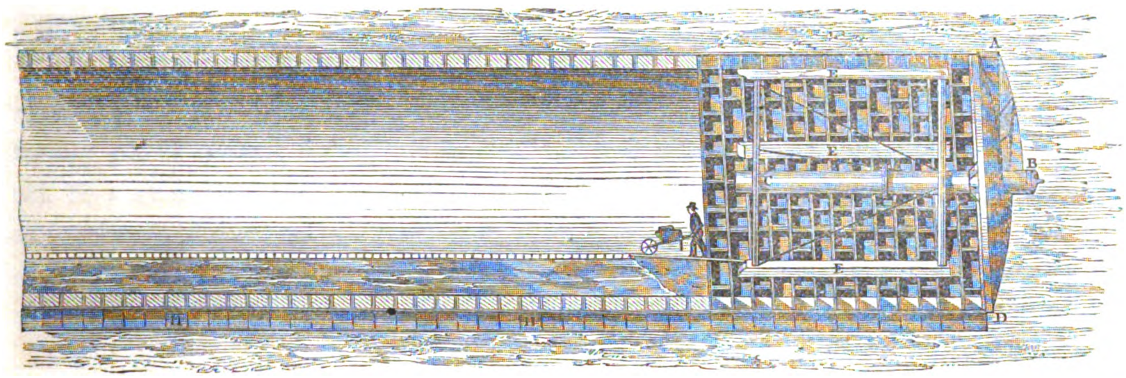
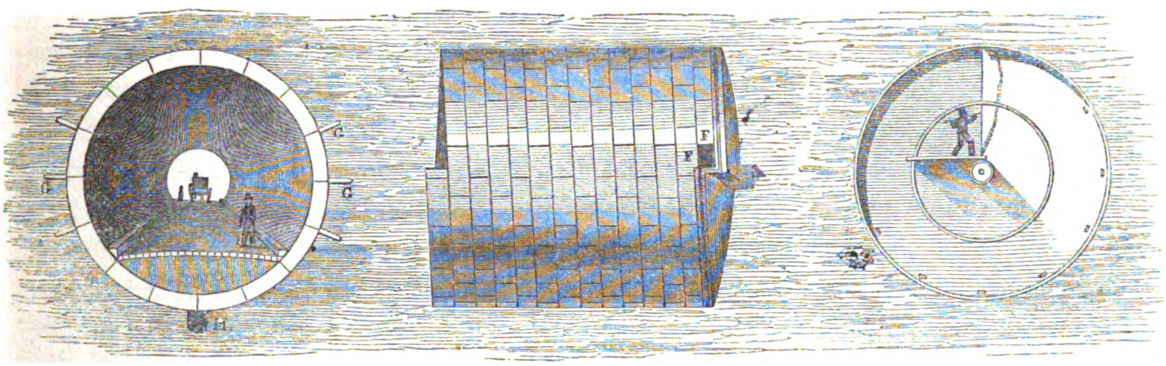


Fig. 2. Fig. 3. Fig. 4.



The head or forepart A D is made in the form of a common auger, such as is used by carpenters for boring wood; it turns on a large hollow axis, C B, which is supported and kept in a correct direction by means of the long circular frame E E, which is moved along as the head progresses, and which aptly represents the body of the worm. As the head turns, the edge A B cuts its way through the ground, which is excavated sidewise, as shown in figure 4, and it slowly advances in consequence of the screw form of the head.

It now remains to describe the manner in which the tunnel is formed in the space

Digitized by Google

thus eaten away, as it were, by this immense artificial teredo; and here we find the analogy between nature and the design still hold; for as in the former, the worm as it proceeds leaves a peculiar secretion behind, which soon hardens, and forms a species of wall, so in the plan, as the head or worm A D advances and leaves a small space between itself and the end of the tunnel, (as seen in fig. 3,) a small casting of iron, F F, is inserted, and brickwork afterwards added, until the sides are of a sufficient strength. If the ground through which they passed was of too soft a nature to support the tunnel safely, small piles, G G, could be driven out sidewise from between the castings, as shown in figure 2. A small drain was to be carried along beneath the tunnel, to lead off any water that might be met with in the course of the excavation.

In the above sketch, figure 1 is a longitudinal section taken through the middle of the tunnel, showing the circular framing and auger, and a portion of the tunnel completed behind; figure 2 is a tranverse section, giving a perspective view of the arch finished; figure 3 is an external view of a portion of the tunnel, showing the iron castings and the auger head; and figure 4 is a view of the auger, as seen from the tunnel, with the circular frame removed, for the purpose of exhibiting the mode of excavating the ground.

This method of tunnelling would probably have succeeded for small tunnels, and perhaps for those on a larger scale, but Sir Isambart, fearing that in a tunnel of a large size the friction of the ground against the external front surface of the worm would prevent its being freely turned, afterwards modified his plan, and instead of having the head or shield to turn, he proposed to propel it forward by means of screws.

The form of the tunnel, as first proposed by Sir Isambart, was circular; and in ground of a homogeneous nature and equally dense throughout, this form would be the strongest and the most economical. Where, however, the ground consists of horizontal strata, of varying density, and pressing principally in a vertical direction, and very irregularly, the rectangular form is the best adapted both for strength and facility of formation.

The form of the present tunnel is shown in Plate 1, which is a transverse section of the brickwork and ground, showing the strata met with in forming the tunnel, when lying in their natural order and undisturbed. This section is taken through the middle of the tunnel, at its lowest point in the deepest part of the river, and shows the relative position of the high and low water lines, and the bed of the river, with regard to the top of the excavation, at that part where the depth of ground above the tunnel is the least. It will be seen by an inspection of this Plate, that the body of the tunnel externally is rectangular, and contains two parallel archways, of an irregular oval form

Digitized by Google

within it, leaving a wall of brickwork between the two; the upper portion of each archway is semicircular, having a span of fourteen feet; the sides are segments of circles, the outside struck with a radius of thirty-one feet six inches, and the inside pier with a radius of fifty-eight feet, the centres of both being situated in the same line as those of the semicircular arches; the invert is struck with a radius of seventeen feet, the centre being situated in the crown of the upper arch. The thickness of the brickwork at the crown is two feet six inches, and the same at the invert, which is laid upon three-inch elm planks; the external piers are each three feet thick, and the middle one, three feet six inches; the number of bricks used per foot run, was about six thousand.

Small cross arches were formed at every eighteen feet, which afford the means of an easy and frequent communication between the two tunnels. From the manner in which the tunnel was built, by successive additions of nine inches at a time, it would have been impracticable to have built these cross arches while making the tunnel; the middle pier was therefore built quite solid, and these doorways were cut out afterwards, which, although a very laborious operation, afforded an excellent proof of the soundness of the brickwork; the upper portion was cut away sufficiently to allow of a nine inch ring being turned, and the old work made good up to it.

A double archway possesses many advantages over a single one, especially where the passage of carriages in both directions is required, not to mention that a single tunnel of sufficient internal capacity to allow of carriages passing, and at the same time leaving sufficient space for the convenience of the foot passengers, would have been considerably higher than the present; and inasmuch as the near proximity of the river above, and an extensive quicksand beneath, necessarily limited the height, from this cause alone would be found impracticable.

The cross arches not only afford the means of communication between the two tunnels, but also add much to their architectural effect and pleasantness, serving to enliven and relieve a walk which might otherwise be thought monotonous and unvaried; and an additional advantage which they afford, and is sure to be appreciated in the present age of utilitarianism, is their appropriation as shops, which promises to be a source of some little profit, and certainly a very enlivening feature to the tunnel.

The brickwork of the tunnel was formed by successive additions, or rings, as they were termed, of either a whole or half a brick at a time, without any bond whatever between them. The manner in which the bricks were disposed in both these methods of construction is shown on the section already referred to (Plate 1); the right hand half

Digitized by Google

showing the manner in which the bricks were placed when working by nine inch, and the left hand by four and a half inch rings. In the greater part of the tunnel the arch is composed entirely of brickwork, the first or inside ring being built with perfectly pure cement, and all the other part with half sand and half cement.

Some fears have been entertained (from the known proximity of an extensive bed of quicksand) for the stability of the foundation of the tunnel; it is, however, sufficient to dispel these to mention, that the whole weight of the brick structure of the tunnel does not amount to above a third of that of the ground which it displaces; and that in consequence of the peculiar *quickness* of the ground, by which it presses almost equally upwards or downwards, the tunnel possesses a considerable degree of buoyancy, having rather a tendency to rise than to sink.

During the early part of the year 1824, extensive and very accurate surveys were made of the bed of the river, and careful soundings taken on the intended line of tunnel; in addition to this, experienced persons, quite unconnected with either Sir Isambart or the Company, and uninterested in the success of the scheme, were employed to make borings; and in July, the Directors, in their first report to the subscribers, stated, that "They have now the satisfaction to inform you that the result of thirty-nine borings, made upon two parallel lines, across the river, has fully confirmed the expectations previously formed; there having been found upon each a stratum of strong blue clay of sufficient depth to ensure the safety of the intended tunnel.

"The ground on the Surrey side of the river, near to Rotherhithe Church, was also bored, and a deep well being sunk on the north side for a parochial purpose, gave a result of a most encouraging nature."

The tunnel, as first proposed by Sir Isambart, although precisely the same in form as the present, was only thirty-four feet wide, and eighteen feet six inches high; but in consequence of the very favourable nature of this report, he enlarged the tunnel to its present dimensions, thus increasing the cubic dimensions of the brickwork in the proportion of two to three, and the area of the excavation in the ratio of seven to nine; and as the estimate had been calculated upon the smaller dimensions, this alteration occasioned a very considerable increase in the cost of the work, and was one of the principal causes of the insufficiency of the first estimate.

The Act incorporating the Company received the Royal assent in June, 1824, immediately upon which preparations were made for commencing the Rotherhithe shaft. The mode in which this shaft was constructed, and sunk, is, in principle, similar to that very extensively employed for sinking wells. From the extreme looseness of the ground, and the abundance of the land-springs, an open excavation of this size, to any depth, would have been quite impracticable, as the most costly means

Digitized by Google

must have been resorted to, in order to support the ground, and even with these precautions the surrounding buildings would have been in considerable danger.

From the novelty of the attempt to apply this principle in the construction of so large a structure, very considerable interest and attention was excited. Being looked upon as the first step of a hazardous, and, at that time, extremely doubtful undertaking; the very possibility of commencing the tunnel depending, indeed, upon the success of this operation; and the former attempts (on so much less a scale) having failed, many doubts were entertained of its ultimate success; and even amongst the profession, not a few unfavourable opinions were expressed.

The brick structure was built upon a strong curb, formed of timber and iron, and sunk to its place by excavating the ground from beneath it, the brickwork being added to the top, as the underneath part sunk in the ground. The Rotherhithe shaft was successfully sunk in this way, to a depth of forty feet, and although from various causes it was found impracticable to proceed lower upon this principle, and underpinning had to be resorted to for its completion, the result of the experiment was considered to be highly satisfactory. The same mode was adopted of sinking the shaft on the Wapping side, and experience having pointed out the causes of difficulty in the former attempt, this second structure was sunk to its entire depth (above eighty feet) with perfect ease, and at less than the estimated expense.

Some delay, in the commencement of the shaft, was occasioned by a dispute between the Tunnel Company and the proprietors of the ground upon which it was proposed to erect it. But possession having been at length obtained, and the site determined upon, all the buildings standing upon it were immediately removed, and the surface of the ground having been levelled, operations were commenced on the 16th of February, 1825, by driving a circular row of short piles, to serve as a temporary support for the structure, and prevent any irregular or partial settlement while the wall was being built.

The curb upon which the brick tower was constructed, (a transverse section of which is here given,) consisted of a ring of cast-iron, A, fifty feet in diameter, three feet deep, and ten inches wide on the top edge, made in forty-eight segments, firmly bolted together with flanges; the lower edge being slightly bevelled, to enable it to penetrate the gravel with greater facility. Upon the top of this was placed a wooden curb, B, composed of sixteen segments, each of which was firmly bolted to the iron curb by nine screws; this latter curb, which was twelve inches thick and three feet four inches wide, was made in two thicknesses, the upper one being so placed as to cover the joints of the lower, for the purpose of obtaining greater stiffness.

Digitized by Google

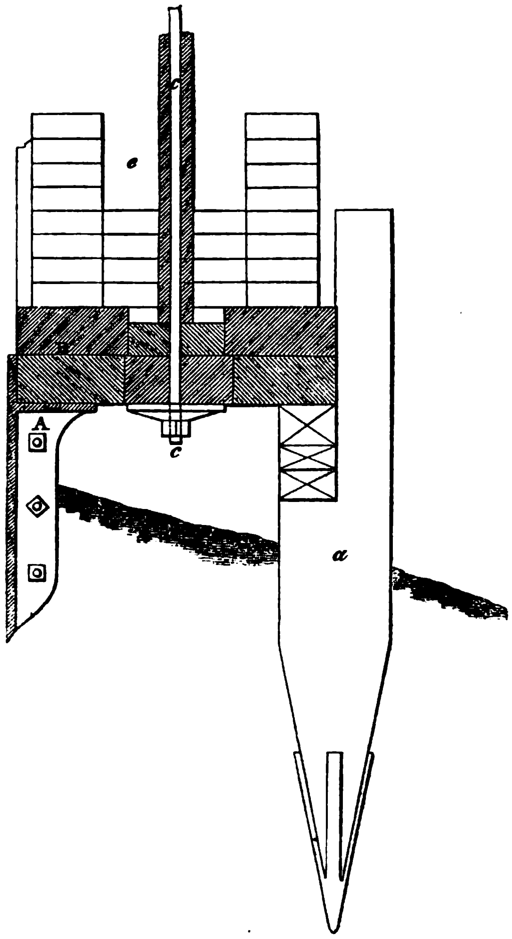


Plate 2 contains a sectional elevation and plan of the shaft while in the course of construction. In the plan, fig. 2, a portion of the brickwork is removed, for the purpose of affording a view of the two curbs. Upon the upper side of the wooden curb a circular channel or trough, two inches deep and twelve inches wide, was left for the purpose of forming a more perfect bond with the brickwork.

It has been already mentioned that a circular row of piles (shown at *a a*, Plate 2, and in the preceding wood-cut,) had been driven on the inside line of the intended shaft; these having been completed, the iron curb was put together outside of them, and upon this the second one of timber; upon the completion of which, wedges were driven in between the latter and the top of the piles, so as to bring the whole weight of both curbs upon them. These piles were intended to assist in supporting the weight of the shaft, until it had been sunk sufficiently into the bed of gravel to obtain an even bearing.

All the necessary preparations having been made, the ceremony of laying the foundation-stone, and thus giving a date to the undertaking, was fixed for the second of March; on which day, at one o'clock, it was performed by Mr. Smith, the Chairman of the Tunnel Company, in the presence of a very large assemblage, and, at the suggestion of Sir Isambart, a dozen bottles of wine were securely corked and sealed, not to be opened until the other side of the river should have been reached, and the tunnel completed. These bottles were carefully preserved, and although at one time there appeared to be very little chance of their ever being opened, Sir Isambart has lived to see the day when, the object of his long and anxious care having been at length accomplished, they were triumphantly opened, to drink, in their contents, the completion of the work, and a long life and health to the engineer, to enjoy the laurels which he had so hardly earned.

As the brick structure in the process of sinking would be exposed to many ir-

Digitized by Google

regular strains, great strength and stiffness were deemed necessary in its construction. It was therefore determined to build the wall, which was three feet thick, in the best Roman cement, and to insert, at every fourth course, (commencing at the twelfth from the bottom,) a circular hoop of wood, *b b*, Plate 2, three inches square. In addition to these, twenty-four wrought iron bolts, *c c*, one inch and a half square, cased in wood, and the same number of wooden rods, *d d*, four inches square, and shod with iron bolts at each end, were inserted vertically in the centre of the wall, forming a circular row of bolts, alternately wood and iron; the brickwork was thus securely tied together, both in a horizontal and vertical direction.

Before commencing the brick structure, it was determined to sink the curb until it had an even bearing upon the bed of gravel, and this operation was effected in the following manner. Timber blockings being inserted under the curb, in the intermediate spaces between the piles *a a*, long wedges were driven in between them and the curb, until the weight of the latter was entirely supported by the blockings; the short piles *a*, were then driven down a few inches by a small pile-driving engine, and the ground having been eased round the outside of the curb, it was slowly sunk by driving back the wedges until it was once more brought to bear on the piles; the blockings being then removed, the ground was excavated about nine inches, upon which they were replaced, and the long wedges again inserted, after which the short piles were once more driven down, and these operations were successively repeated, until the curb having been sunk about four feet ten inches from its original position, through a loamy soil, was brought to bear upon the bed of gravel already referred to. Before proceeding further, it was determined to load the curb with a dry wall composed of bricks, and sand, that its weight by condensing the ground, might prevent any irregular settlement during the building of the permanent structure: this wall was raised to a height of seven feet, and being on an average four bricks and a half thick, must have weighed, with the curb, about two hundred and fifteen tons.

The blockings having been removed, and the short piles driven down, the whole of this weight was brought upon the edge of the cast-iron curb, which sunk perfectly level several inches into the gravel. In this state, it was slowly lowered, by picking the gravel away from the edge of the curb, care being taken that it preserved its true level, which was very easily restored, where it happened to deviate, by picking a little more on one side than another; although its descent was very slow and gradual, the cast-iron edge crushed the gravel with considerable force, making a noise resembling a loaded cart passing over a gravel road. Having been sunk in this manner perfectly level to a depth of six feet four inches, and having a good bearing upon the gravel, it was determined to take down this temporary wall, and to com-

Digitized by Google

mence the permanent brick structure. Having been left the whole of one night with the edge of the curb resting on the gravel, although its weight, as before stated, was upwards of two hundred and fifteen tons, it was found in the morning not to have settled more than one-sixteenth of an inch: it was feared from this circumstance that it might be earth-bound, but upon picking the gravel from one side to correct a slight deviation in the level, it sunk without any difficulty.

The blockings having been again introduced under the wooden curb, and wedges driven firmly between them, the whole of the bricks and sand were removed, and a circular scaffold was raised on both sides of the intended wall. The vertical bolts *c*, and rods *d*, before described, were next put in their places; the lower end, which passed through the wooden curb, being firmly secured by a large plate and nut; and they were kept in a true vertical position by being lashed to cross pieces fixed to the upper part of the scaffold. Every thing having been thus prepared, the brickwork was commenced by raising two circular parallel walls, with bricks endwise upon the wooden curb, leaving a circular trough or channel, eighteen inches wide and four courses deep, between them, as shown at *e*, Plate 2, and the wood-cut at page 9. This space having been filled with a thin cement grouting, (composed of three parts Roman cement and two parts of sand,) the bricks were laid swimming as it were in it; and by adopting this means the joints were perfectly filled by the cement, and a very solid structure formed. Particular care was bestowed upon the choice of the bricks and cement, every cask of the latter being proved, and none used but such as set immediately; it was likewise gauged in small quantities, and with the greatest care, in the proportions just stated; and of the former, none were used but such as were hard burnt, without any regard to the unevenness of their surface. Cast-iron pipes were inserted in different parts of the wall for the purpose of leading off and diverting any water which might be met with in the course of the work. The outside of the shaft was covered with a coating two inches thick, (composed of half cement and half sand,) intended for the double purpose of rendering the wall more impervious to the land-springs, and by smoothing the surface to ease and facilitate its descent.

The shaft was carried up in this way to a height of forty feet, when a second timber curb of similar dimensions to the lower one was placed upon the top, being bedded in Roman cement, and firmly bolted down to the brickwork, by plates and nuts on the top of the vertical tie rods *c* and *d*. The whole of this structure, containing upwards of 17,700 cubic feet of solid brickwork, occupied only three weeks in building; and during that time, the curb was found to have settled only one-quarter of an inch.

After the brickwork was completed, and the upper curb fixed, a timber framing

Digitized by Google

and floor was put into the shaft, and the scaffolding used in its construction removed. It was intended to have placed on the top of this timber floor, for the purpose of pumping out any water which might be met with, and for raising the excavated earth, a thirty-horse high pressure steam engine, on a new construction, peculiarly adapted for this kind of work, which had been lately patented by Sir Isambart, and was being constructed by Messrs. Maudslays; but from some unexpected causes of delay in its execution, it was not completed in sufficient time; in consequence of which, temporary hand gear was erected in its stead, preparatory to the shaft being sunk.

The whole of the preparations being completed, the first proceeding in sinking the shaft, was to remove the blockings, and bring the curb to bear upon the ground; which was a work of peculiar hazard, requiring the greatest caution and circumspection, to prevent any irregular settlement. The men were ordered to proceed on two opposite points at once, and, having removed one of the blockings, immediately to supply its place with gravel well rammed in under the curb; upon the top of this gravel, planks were placed, and wedges driven in between them, and the under side of the curb. By proceeding in this manner, in the course of a few hours, the whole of the blockings were removed, and the short piles *a a*, having been driven down, the whole structure, weighing upwards of nine hundred tons, was brought to bear entirely on the gravel.

From the report made by those, by whom the small shaft for the driftway was sunk, of the difficulties which they experienced in passing through the quicksand, it had been apprehended that great precautions would be necessary in the operation of sinking the present one, which was on so much larger a scale; and it was intended to have had stays and guides on the exterior of the shaft, to regulate its descent, in case, from the ground being softer on one side than the other, it might have had a tendency to sink unequally. From the regularity, however, with which the curb had been sunk thus far, these were not deemed necessary, and it was therefore determined to proceed without them. Sir Isambart likewise provided a bucket chain, instead of a pump, for raising the water, intending, if any large body of quicksand had been met with, to raise it by that means, in a similar manner to dredging. From the firmness of the ground, however, it was found better to excavate it in the usual manner, and therefore the bucket chain was not used.

The framing and machinery having been completed, all the piles, planks, &c., were removed from under the curb, and the excavation proceeded with,—the shaft sinking very gradually, as the ground was removed. It was found to sink generally very regularly, and any deviation from its level position was easily corrected by removing the ground more from underneath one side than the other.

Digitized by Google

The ground through which the shaft had to pass, to a depth of fifteen feet, was gravel, containing very little water, which was easily kept under by the bucket chain worked by hand. At that depth, however, some difficulty was experienced in consequence of its becoming earth-bound, for although all the ground had been removed from the edge of the curb, the structure did not sink. In consequence of this, a circular trench was made, by removing the ground round the outside of the shaft, and inserting clay and water for the purpose of lubricating the surface of the brickwork, and likewise of softening the ground; and the water was also allowed to rise in the excavation for the same purpose. By these means, the shaft sunk ten inches in about two hours, and on pumping out the water, and examining the cause of obstruction, it was found that one of the segments of the cast-iron curb was broken, and another slightly forced in, by the pressure of the ground; these having been repaired, the shaft continued to sink gradually without further difficulty.

On the 29th of April, the whole structure sunk suddenly several inches, with a very considerable surge, the sensation of which was described by those who were on the platform, to have been like that of the movement of a ship. Upon taking the levels of the opposite sides of the shaft, it was found to have sunk four inches more on the east, than on the west side; and on examining the state of the ground at the bottom of the excavation, the cause of its sudden and irregular descent was immediately discovered. On the west side the ground still consisted of a stratum of large gravel stones, two or three inches in diameter, and so hard as to prevent the curb from sinking through it; while on the east side, the curb had entered into a bed of loose sand, in which it was found deeply buried. The overhanging of the wall was soon corrected, by picking away the gravel on the east side.

As the excavation was carried to a greater depth, the influx of water was found to increase, causing the operation of pumping it out by hand to be very laborious and expensive; thirty-six men being required both day and night for that purpose. The labour of raising the excavated earth likewise became very great as the depth was increased; and as the steam engine before mentioned, which was being constructed by Messrs. Maudslays, was not likely to be ready for some time, it was determined to hire a twenty-horse engine, to be put up temporarily in its stead. This was accordingly done, the progress of the work being necessarily slow, from these serious causes of delay.

A small experimental well had been made about twelve feet from the outside of the shaft, which was carried down in advance of the larger excavation, for the purpose of exploring the ground; and it is rather a remarkable circumstance, that the water uniformly remained higher, by several feet, in the well than in the shaft, since it might

Digitized by Google

have been expected, that the large excavation would have drained the well, which was situated within so short a distance.

On the 10th of May, the centre of the excavation reached a bed of quicksand, through which a rod could be pushed with ease five feet six inches, but at that depth a bed of strong blue clay was found. On the 14th of the same month, the steam engine was started, there being at that time fifteen feet of water in the shaft, and the influx was found to be so abundant, that hand pumps were required to assist the engine. By the 18th, the curb had passed through the quicksand, having sunk forty inches in two days, and had entered a bed of loose gravel about fifteen inches thick, beneath which was situated the blue clay. On the next day, the shaft having sunk twenty-three inches more, reached the clay upon the east side, the water being still very abundant from the side nearest to the well; it was therefore determined to deepen the well, in order to relieve the shaft, but as the curb sunk into the clay, the quantity of water was found to diminish very considerably, and in a few days had lessened so much, that the engine pumped it out with great ease. It had been hoped that when the shaft reached the clay, the water would have been almost entirely stopped, but it still came rather abundantly from the west side, washing away the clay from the edge of the curb; to prevent this, holes were drilled in the upper part of the cast-iron curb, for the purpose of giving a vent to the water, and diverting it from below. A heading was also carried from the well, and round the lower part of the shaft on that side, for the purpose of puddling behind the wall. Small piles or stakes, about twelve inches long, were likewise driven horizontally into the clay, under the edge of the curb, to prevent the loose gravel being washed down from above. In consequence of these measures, the water was partially stopped, although a considerable quantity still found its way under the curb.

The shaft not having sunk for some little time, although the ground had been cleared more than two feet from under the curb, it was loaded with fifty thousand bricks, and the water allowed to rise in the inside to soften the ground; by these means it sunk slowly about two feet, and being then only seven inches above the height prescribed by the Act of Parliament, it was determined not to endeavour to sink it any lower, but to proceed with the remainder by underpinning.

The underpinning was accordingly commenced on the east side, that being the deepest in the clay, and the freest from water. The ground having been excavated to a depth of eight feet six inches below the bottom of the shaft, planks were laid down, and the wall was carried up upon them, in a length of twelve feet, and varying in thickness from four feet to four feet six inches, the inner side being built flush with the wall of the shaft, and the outside being worked back to the ground, and well

Digitized by Google

filled in with cement, gauged with sand in the same proportions as that used in the construction of the shaft. This length, which was carried up to within six or eight inches of the edge of the cast-iron curb, having been successfully accomplished, it was determined to commence another similar portion; but owing to an accident occurring to the flues of the boiler, the engine could not be kept at work, and the water rose twenty-one feet inside the shaft. As soon as the excavation was again clear, the men were put to work on the second length of underpinning, but owing to the water having softened the clay, the gravel came down twice, from behind the curb, on the north side. To obviate this, shavings were forced up into the gap, and short stakes or sheet piles, driven into the clay horizontally, close under the edge of the curb; and this having been found to answer the purpose effectually, Sir Isambart ordered it to be done all round the edge of the curb, previously to proceeding any further with the underpinning. By building very cautiously, in this manner, the whole ring of brickwork was completed in a few days, although from the engine again stopping in the night, another considerable slip of ground was occasioned on the south-east side. To effect a more perfect junction with the shaft, and to prevent the ground from being disturbed, Sir Isambart determined to sacrifice the cast-iron curb. The underpinning was therefore carried up to its edge, the last two outside courses being laid in pure Roman cement, and as soon as this was sufficiently set, caulking was forced in under the edge of the curb, to keep the water back; the waterways and pipes, which had been inserted in the wall of the shaft, for the purpose of diverting the water, being left open, until the whole of the work had become quite solid.

This having been effected, the second ring of the underpinning was commenced at a depth of fifty-three feet six inches below Trinity high water, and eight feet three inches below the bottom of the first ring. The ground consisted of clay mixed with shells, and the lower portion had been indurated by the action of water, so as to form almost a rocky substance. This second ring was laid upon sleepers, and stakes were driven horizontally into the ground, and built into the wall for the purpose of preventing its settling. As the underpinning progressed, the influx was found to diminish in quantity, although, in consequence of the steam engine frequently failing, great inconvenience was felt from the water rising inside the shaft. An opening thirty-four feet six inches wide was left on the north side of this second ring, through which the shield was to pass out of the shaft.

On opening the ground to a greater depth, it was found to consist of a very hard dense stratum, composed of gravel, mixed with sand of a very green tint, together with chalk, and an ochreous earth of a red colour. As the ground appeared so firm, and quite free from water, it was determined to complete the whole remaining depth of

Digitized by Google

twelve feet at one operation, and the excavation was accordingly carried down to that depth, the ground remaining of the same character, but the lower portion containing more gravel and a little water. In order more completely to drain this stratum of gravel, before commencing the foundation for the last ring of the underpinning, and the inverted dome intended to form the bottom of the shaft, Sir Isambart had a small well sunk through it, into the next stratum, which was found to consist of silt and sand, containing much water, and upon sinking the well into it, the silt rose or boiled up five feet; it was therefore determined to go no lower, but to commence the foundation at a depth of sixty-five feet six inches below Trinity high water. To ensure a good base, small piles two feet six inches long, and six inches apart, were driven into the gravel with a sledge hammer, and a rough grouting thrown over the whole, so as to form an even surface.

As but little water had been met with, and the ground was found to support itself so well, Sir Isambart did not think it necessary to build this lower portion of brick in cement, as the other had been done, but determined upon using rag-stone, as a kind of rubble, laid in a thin mortar, composed of one part Roman cement, two of lime, and three of sand. The work was therefore carried up in this manner, the inside being lined with two courses of bricks laid in Roman cement, as shewn in Plate 3: an opening of similar dimensions to that left in the last portion, was likewise left in this, with the exception of the lower part or foundation, which was carried all round, for the circular inverted dome, which forms the bottom of the shaft to spring from.

The thirty-horse steam engine which Messrs. Maudslays had been making was fixed and started by the end of July, and was found to work perfectly well, and to this was connected a much larger pump, which was found to be a considerable improvement; long and frequent delays having been occasioned by the stoppages of the old engine.

The underpinning having been completed in the manner described, Sir Isambart next proceeded to the construction of a cesspool or pumping well, at the bottom of the shaft, which it was his intention to carry down to a greater depth than the lowest part of the tunnel, so that by carrying a small drift from it, under the invert of the latter, any water that might be met with in the progress of the work, might run back to this well, and thence be pumped up by the powerful force-pumps which were to be fixed in the shaft. Before commencing the well, borings were made in the middle of the shaft, by which it was found that at a depth of seventy-two feet below Trinity high water, there was a stratum of quicksand rather more than a foot in thickness, from which a very large quantity of water proceeded; beneath this for twelve feet, good workable ground was met with, but after that, at the depth of eighty-

Digitized by Google

five feet, it was found that there existed a very extensive body of quicksand, of a light slate colour, and containing a great quantity of water; thus confirming the opinion of several eminent geologists, who had warned Sir Isambart of its existence, and advised him to keep the excavation for the tunnel as near the bed of the river as possible, on that account.

Having thus ascertained the nature of the ground, Sir Isambart decided upon not carrying the cesspool to so great a depth as these lower springs; but as it would be necessary to pass through the upper ones, which were ascertained to be very copious, he determined upon sinking it with a curb in the same manner that the first portion of the shaft had been effected; a very stiff cast-iron curb, twenty-five feet in diameter, was accordingly made and lowered into the shaft.

Previously, however, to commencing this, Sir Isambart had a second well, five feet square, made in the bottom of the shaft, for the purpose of exploring the ground, and obtaining a more extensive knowledge of its exact nature, than could be afforded by borings only; and a further object was to drain the ground, and thus render the large excavation for the cesspool drier. This well was immediately proceeded with, and carried down fourteen feet without any difficulty; but on approaching the first bed of quicksand, a sudden burst of water and sand took place, to stop which several large stones (which had been provided, in case any thing of the kind should occur) were immediately thrown in upon the ground. It was found that the water had come from the first well, (already described,) and the boring in the middle of the shaft, both of which were immediately drained, although two pumps had previously been required to keep them free from water. This circumstance affords a remarkable illustration of the facility with which water makes its way through these thin beds of sand, these two wells being situated about twenty feet apart. In order to carry the square well down to a greater depth, the old well was deepened for the purpose of diverting the water from the former, which having been effected, the planks forming the sides of the square well were driven down with a small pile-driving machine through the sand, which, as before stated, was only about a foot in thickness.

This having been accomplished, the operation of sinking the curb for the cesspool was next commenced; after it had been lowered about five feet, and while proceeding with the removal of the ground near the boring pipe, which consisted of a stratum of gravelly soil, mixed with clay and green sand, it suddenly gave way, leaving a cavity several feet deep, the sides of which were firm and perpendicular; this was doubtless occasioned by the underneath strata having been gradually washed away by the constant influx from the springs, so as to leave a cavity, into which the superincumbent earth, upon being disturbed, had fallen. While the cavity was open, a small spring

Digitized by Google

was seen oozing from the sides, at about seventy-five feet; it required about forty cubic feet of gravel to fill it, but as all the soluble parts were washed away by the force of the water, the actual size of the cavity may be estimated at about twenty cubic feet. After this the excavation was continued, and sheet piles were driven all round the outside of the curb, to which they were firmly bound by a hoop of iron, a second curb of timber being put in a few feet above the lower one, to keep the piles in place. As this excavation approached the thin stratum of sand, the water boiled up in several places, and all round these spots large stones were thrown, to prevent the springs from washing away the ground. By proceeding very cautiously in this manner, and keeping the bottom covered with rubble stones, they succeeded in passing through this bed, and sinking the curb to a depth of seventy-seven feet; but finding that the water slightly increased, it was determined not to sink it any lower, but to commence the invert of the cesspool forthwith, the lowest part of the excavation for which, in the centre, was about eighty feet below Trinity high water; but before this could be begun, the ground suddenly gave way outside the curb, on the south-west side, to a very considerable extent; the sides of this cavity were quite perpendicular, the same as that which occurred before at the boring pipe, and was owing to the same cause, namely, the under stratum being washed away by the springs. This cavity was filled in with puddled clay, well rammed, and small sheet piles were driven horizontally, underneath the edge of the curb, to keep the ground in its place, and prevent any recurrence of the same accident.

A quantity of loose stone was thrown over the bottom of the excavation, previously to commencing the masonry, and wherever the ground was soft, short piles were driven; upon this the invert for the cesspool was commenced in rubble, laid in a mortar gauged in the same proportions as that used for the foundations of the shaft. A large cast-iron pipe was inserted in the bottom, to allow the water to have free vent, until the whole was completed; and a number of smaller leaden pipes were also inserted, wherever a spring was met with, for the same purpose. The most difficult part of the work—the invert and foundation, having been successfully accomplished, very little difficulty was experienced with the other part, and the side wall of the cesspool did not occupy much time in building. In order to save the expense of carrying a driftway under the tunnel, for the purpose of draining the excavation, it was determined to have in its stead a pipe driven forward horizontally, (in the same way that wells are bored,) and a large cast-iron pipe was built into the north side of the cesspool for that purpose. The wall of the cesspool having been carried up to a sufficient height, the inverted dome intended to connect the cesspool with the shaft, was com-

Digitized by Google

menced in rubble work; the same precautions, of driving short piles, and grouting, being adopted wherever the ground was at all loose.

By the middle of October, both this invert, and the dome over the top of the cesspool, were completed, and thus the shaft was securely finished, as far as regarded the lower part; the only thing remaining to be done, was to remove the wooden curb, and connect the brickwork of the upper portion of the shaft with the underpinning; and this, with a little precaution, was successfully accomplished, without occasioning any disturbance in the ground behind the curb. In order more effectually to secure the ground round the outside of the shaft, at the junction of the old and new work, and to remove the cast-iron curb, if practicable, a well was sunk outside of the shaft, on the north side, down to the level of the curb, and a heading carried from it round the wall, just above the curb; by this means they succeeded in extracting some of the segments of the curb, and making good the brickwork, after which they securely puddled round the junction of the old work and the underpinning. While this was being effected, four powerful force pumps, made by Messrs. Taylor and Martineau for the tunnel, were fixed at the bottom of the shaft, and connected by toothed gear with the thirty-horse steam engine. The different parts of the shield were also lowered, and by the end of October the whole twelve frames had been put up in their proper position (as shown in Plate 3,) in front of the opening which had been left in the wall for their passage out of the shaft; in consequence, however, of the tunnel being commenced about five feet higher than had been originally intended, a very considerable mass of the wall had to be removed, to give sufficient room for the upper part of the shield to pass.

Plate 3 is a sectional elevation of the shaft and cesspool, as completed, showing the position of the shield preparatory to its being moved out of the shaft, and also the various strata as they occurred in their natural order, and of which the following brief description may not be uninteresting. The figures on the left hand of the plate express the depths below Trinity high-water line, (with which the surface of the ground happened to coincide,) at which the several transitions of strata occur; and the letters are attached for the purpose of reference. The first five feet from the surface, consisted of loam and made ground, after which the natural strata commenced; the first of these, *b*, was of gravel about ten feet thick, very firm, and almost entirely free from water; the next stratum, *c*, was a bed of loose sand, about two feet thick, and very full of water; to this succeeded a bed of very coarse gravel, *d*, mixed with large stones, the influx of water while passing through which was so considerable, that it quite overpowered the steam engine, and rendered the aid of hand

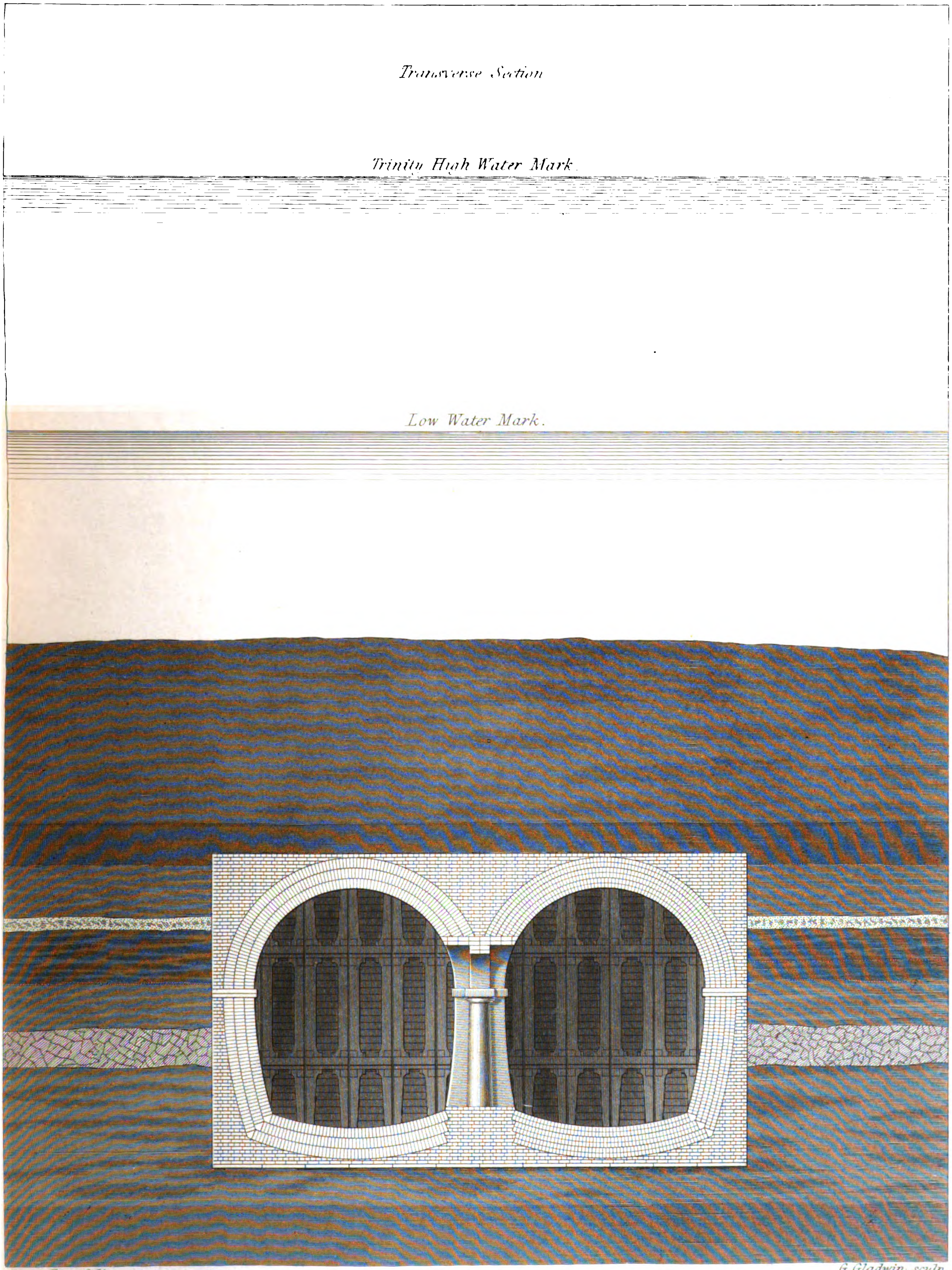
Digitized by Google

pumps necessary; the excavation was next carried through a quicksand, *e*, about five feet and a half in depth, and the influx from which was equally abundant; the next stratum, *f*, which was only fifteen inches thick, consisted of very loose gravel, but did not contain much water; to this succeeded two beds of clay: the uppermost, *g*, nearly nine feet thick, consisted of a very stiff pure clay, of a blue colour; the second, *h*, which was eleven feet thick, was of a more mottled character, and contained a portion of silt and a great number of shells; the next stratum to these, *i*, was a bed of chalk and clay combined, and which had been so completely indurated, as to require the assistance of chisels and wedges to break it up; to this, which was three feet thick, succeeded a bed of green sand and gravel, *k*, four feet and a half thick, of a very firm character; the next four feet, *l*, was also gravel and sand mixed, but of a greener tint, and combined with some chalk and a red ochreous earth, and contained a little water, especially the lower part; to this succeeded nine feet and a half of sandy loam, *m*, very firm and quite free from water, and then a seam or vein of quicksand, *n*, which, although only a foot in thickness, afforded such a copious influx that, as has been already mentioned, some difficulty was experienced in carrying the excavation for the cesspool through it. After passing through the quicksand, however, the ground, *o*, was very firm and dense, consisting principally of gravel of a very green tint, and containing very little water; this stratum was about twelve feet thick, and to it succeeded another bed of quicksand of a light slate colour, of a very dangerous character, and the springs from which were so copious, that Sir Isambart did not consider it prudent to approach within several feet of it. Of the depth to which this quicksand really extends, no accurate knowledge exists; but the same bed has been stated by the geologists, who warned Sir Isambart of its existence, to have been found in other localities upwards of fifty feet in depth: and there can be no doubt, from the great quantity of water which it contains in the neighbourhood of the tunnel, that it is there equally extensive.

The whole operation of constructing the shaft and cesspool, including the removal of the curb, and the erection of the machinery and pumps, as well as the shield, occupied about eight months; which will not appear long, when we consider the difficulties which arose from the loose and dangerous nature of the ground, and the frequent delays occasioned by the inefficiency of the first steam engine. The interest which was excited at the novelty of this operation, was so considerable that the works were daily visited by numbers of persons anxious to witness the descent of the shaft; and a gallery was erected in its interior, from which they could observe the operation, without occasioning any interruption to the work.

Digitized by Google

Digitized by Google

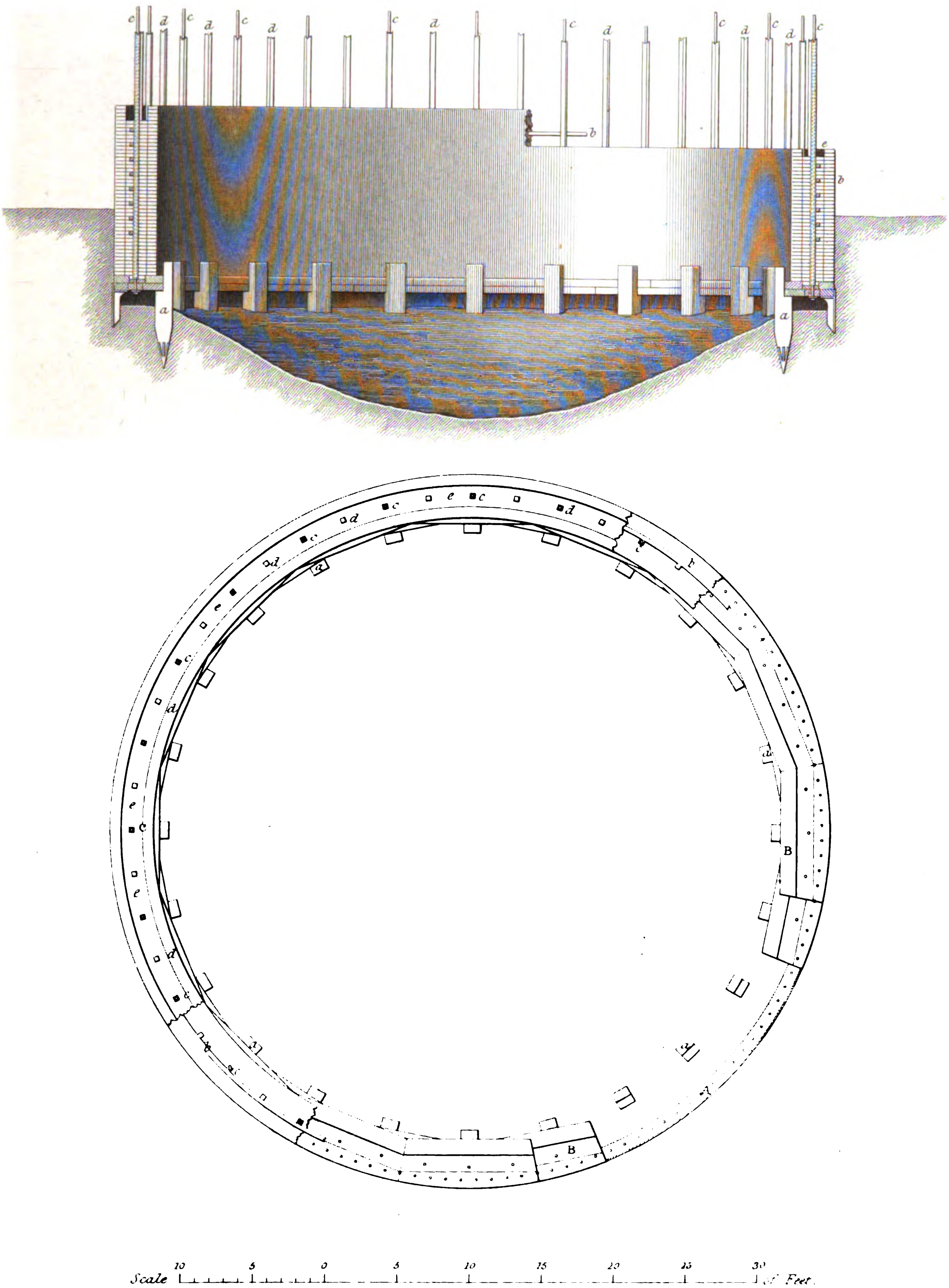


Henry Law, delin.
G. Gladwin, sculp.

London: John Weale, 1845.

Digitized by Google

Plan and Section of the Rotherhithe Shaft



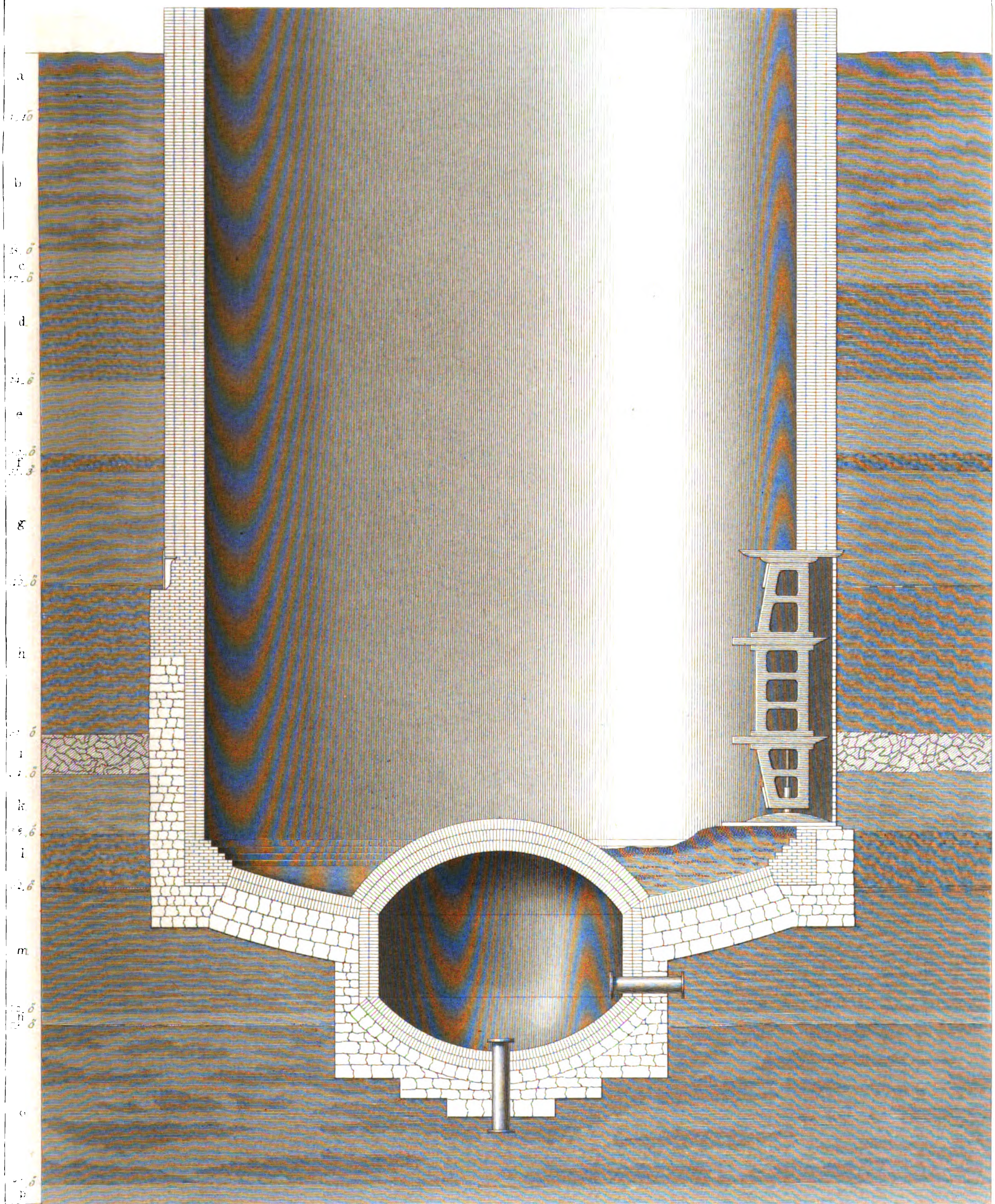
Henry Law delin. *J. Gladwin sculp.*

London, John Weale 1845.

Digitized by Google

Digitized by Google

Sectional Elevation of the Rotherhithe Shaft



Henry Law, delin. G. Gladwin sculp.

Scale 10 5 0 5 10 15 20 25 30

London: John Weale, 18[illegible]

Digitized by Google
Deutsches Museum

Digitized by Google

AN

INQUIRY INTO THE FALL NECESSARY

IN

THE CROSS SECTIONS OF ROADS,

AND

THE BEST FORM OF CROSS SECTION;

WITH

SOME REMARKS ON THE CROSS SECTIONS OF ROADS IN IRELAND, AND THE BEST REMEDIAL MEASURES FOR THEIR IMPROVEMENT.

BY JOHN NEVILLE, C.E., M.R.I.A.

COUNTY SURVEYOR OF LOUTH.

"Do you find practically that almost all the traffic, almost every carriage that runs upon the road, runs upon the sixteen feet in the middle (road thirty feet wide)?—It does; wherever I have seen an instance of cutting into the sides, it has been from putting fresh materials on the centre that they go on the side to avoid it."—*Provis.*

APPENDIX No. 5, to SIR HENRY PARNELL'S TREATISE, p. 398, Second Edition.

IN passing over the county and turnpike roads of Ireland, the engineer cannot fail to observe the great diversity of their cross sections, not only on different lines of roads but on different portions of the same road, as if variety, in this respect, was a principle in their construction. Before entering farther at present into the existing state of the cross sections of the roads of this country, it may be best to show what is required from the cross-surface section of a road, and thence to investigate, by deduction, the best form for that surface. In this investigation the draught, the wear and tear, the drainage of water falling on the roads, and the gradients, are the only elements to be considered; but as the wear and tear, *cæteris paribus*, depend on the draught, it will only be necessary to determine that form of cross-surface section on which the draught is the least possible, and which discharges sufficiently any rain-water falling upon it; external water being kept off by the usual means.

The form of surface which makes the draught upon it the least possible is evi-

Digitized by Google

dently horizontal; as then the weights on opposite wheels of a vehicle are equal, and for physical as well as mechanical reasons, the draught is then a minimum. This portion of the question is therefore easily disposed of.

The greatest quantity of rain which falls during any month in this country, may be taken at five inches deep. This is, I believe, something more than falls in Cork, or any of the south-western counties; and nearly double the mean monthly fall in the north-eastern counties, or in England. If an equal quantity fell each day of the month, one sixth of an inch deep would be the daily fall. The fall of rain is not, however, equal each day. I will take for calculation two inches deep in twelve hours, and a road thirty feet wide, flat at the surface, excepting the tables which are below it, and trace what follows. After the rain begins to fall, the inequalities of surface which exist in the best roads will begin to fill; a portion of the water falling will be absorbed into the road. After some time the lower inequalities are filled, and the water begins to communicate from one hollow to another, finding its own level. Next a thin film of water extends over the whole surface, broken in parts by small projections in it. This film of water discharges itself at what I will call the lips of the water tables by hydrostatic pressure alone, and needs no fall, as will immediately be shown, to do so, as the discharge will be abundantly equal to the supply.

Suppose the film of water rose to be one-fiftieth of an inch deep, this depth of water, while it continued, could not be of the slightest injury to any road. The velocity of discharge due to the lowest particle of this depth is about four inches, and the discharge of water per inch of road per second would be $\frac{2}{3} \times 4 \times \frac{1}{50} = \frac{8}{150}$ cubic inches per second; or $\frac{8}{150} \times 3600 = 192$ cubic inches per hour; or 384 inches, taking both tables. Now in a road 30 feet wide, on which 2 inches of water falls during twelve hours, the quantity that falls per inch of road per hour is $\frac{1}{12} \times 720 = 60$ cubic inches. That is, by comparing the results of both calculations, the discharge, when the water rises $\frac{1}{50}$th of an inch is more than six times the supply on a road thirty feet wide. Considering that I have taken extreme cases, and calculated from them, the advantage of a fall in ordinary roads, from the centre to the sides, to discharge rain water, appears doubtful. When rain ceases to furnish a supply, the film runs off, and a portion of the water in the hollows also, by those little channels which water always finds to run in. The remainder is carried off by evaporation or absorption, the same as if the road was convex. The discharge of rain-water from the surface of a road is by some considered as if it all fell at the centre, and was thence discharged to the side by the transverse fall. This view is, however, incorrect; as the rain falls equally over the whole surface, except in some few instances that do not affect the general question. I shall now consider the cross section on declivities.

Digitized by Google

In order to discharge the water off declivities as soon as possible, without running along them, to the water tables, it appears that the fall to the sides should be dependent on the longitudinal fall. This dependence may be arbitrarily expressed by $t=l$, t being the transverse and l the longitudinal fall. On an horizontal road this would make the transverse section flat; and where the declivities do not exceed one in twenty,—and few, unless old roads, have them steeper,—this formula may be deemed correct enough for inclinations between one in one hundred and one in twenty. I shall afterwards give one that may be more generally adopted. On the supposition of $t=l$, water falling on any part of the road would pass diagonally to the water-tables, its course making an angle of 45° with the centre line, or with the water-tables parallel to it. If there is means of discharge from the water tables at the sides, and that the declivities are very long, this rule for forming the transverse fall may be used; but where there is no means of discharge, or where the inclines are not more than 50 perches long, observation shows that a steeper cross section than on a flat is unnecessary, and that no injury arises from rain-water running longitudinally along the surface until it gets a place to escape, if the surface receives ordinary attention, and is not allowed to wear concave. If external water gets upon a road and runs along it, the case is a different one; but this water I suppose to be excluded by the usual resources. Indeed it may be observed that where all the water is discharged to the tables on steep declivities, and that there are no means to convey it off for long distances, the tables are invariably cut up, unless where paved, and more injury done than possibly could be, if the water ran along the road. In the latter case it would be divided over a large surface into different channels, as tracks of wheels and inequalities of surface, where, from the smallness of the quantity in each and the hardness of the road, no injury could be done. The smallness of the quantity, also, in each such channel, and the number of proportionate obstructions it would meet with in its course, would hinder any increase of velocity that could be injurious; the contrary being the case when all the water runs in the water-tables.

Having shown, mostly by deductive means, that a flat road is the best for reducing draught, and wear and tear, and that a road thirty feet in width requires no fall to discharge sufficiently any rain-water falling on it, I will now proceed by the method of induction, and test this conclusion by observation; I shall also inquire into the deviations from a flat to a convex surface that may be necessary in practice. Here it will be necessary to mention the different cross sections that have been proposed for roads, and to examine and remark upon, in a general manner, the various cross sections of the roads of this country as they exist.

Digitized by Google

The cross sections proposed for roads are of two kinds: a flat segment of a circle, ellipse, or other curve; and a section comprised of two straight inclined lines from the centre to the sides, or from a short horizontal line at the centre to the sides[a]. The draught on the first increases as a vehicle draws near the tables; the draught on the second is the same throughout, unless at or near the centre. In the first more vehicles pass near the centre than in the second, while in the second more pass near the tables than in the first. The second has therefore the advantage of dividing over its surface the traffic more equally than the first, while it is equally efficient in passing off its rain-water. Practically considered, where a road is not too high at the centre, or more than thirty feet wide, these cross sections do not apparently differ; the cross section at first is, however, mostly made to please the eye, it is usually too round, and, unless in very few instances, changes materially when worked upon, and during repairs.

In new roads, the cross section is usually made convex, the whole fall from the centre to the sides, being about one in twenty-four, or six inches rise in a twenty-four feet road. The inclination, however, is often found greater, and arises from an injudicious mode of repairing by constantly darning at the centre, as that place is most worked upon; and from road contractors not keeping the original standard cross section in view, and merely filling worn or displaced ruts as they occur, without previously dressing or picking the adjacent parts. As the greatest traffic is on the central portion of a road, and increases with the convexity, repairs are mostly required at the centre, which soon rises, so as often to increase the transverse fall to one in sixteen in parts. Where this occurs great difficulty exists in keeping up a smooth surface, and several years elapse before the side metalling becomes consolidated, and when it does vehicles seldom drive on it, or only when forced to do so in passing others, or where the traffic is considerable.

In the old roads of the country, the cross sections present every possible variety, unless those portions that have latterly been remodelled. Figs. 2, 3, 4, 5, 6, and 7,

[a] At p. 136, second edition, of Sir Henry Parnell's Treatise on Roads, there occurs the following passage: "In giving a convexity of six inches to a road of thirty feet in breadth, the convexity at four feet from the centre should be half an inch; at nine feet, two inches; and at fifteen feet, six inches. This will give the form of a flat ellipsis." Now a road should never have the form of a flat ellipsis, nor any other like curve, as the fall at the shoulders becomes thereby too steep. The most water passes over the shoulders, and as the power of passing off increases with the quantity, it appears least necessary to have the fall steep there, unless as far as it is required to make a water table. A flat segment is much better than the semi-ellipsis. The fall of two inches in nine feet gives a mean fall of one in fifty-four so far, which, practically, does not differ from the maximum fall mentioned in this paper. The Holyhead road was only worked upon as far as this fall continued, and not where it became steeper.

Digitized by Google

represent some of these, and there are few roads in which either remains constant for any distance, but almost every five perches present a different section. Vegetation may be observed on one portion of a road within six feet of the centre, and at the same distance in another portion the road will be worked upon from shoulder to shoulder. Where vegetation takes place, or places where the road is little worked upon, will be found much inclined. Generally, extension of work over surface, and smooth surface, are to be found together, *united with flatness of cross section.* On all roads, it may be observed, however the cross sections vary, that *cæteris paribus*, the flat sections are worked upon all over, that the traffic is confined as much as possible to the flat portions; that from the greater smoothness of surface and division of wear and tear, less water lodges on the flat, or nearly flat, than on the convex or steep sections. Observation, therefore, furnishes sufficient evidence, as well as theory, that a flat section, or a section nearly so, is for country roads the standard that should be adopted. It may be observed that some of the streets of Dublin are considerably convex, and yet wear smoothly and well. The nature of the traffic on county roads and streets, however, is different. On the first the traffic is mostly longitudinal, of a heavy description, and has the greatest tendency to gridiron a road. The traffic on the second is cross, oblique, and longitudinal, and moves in all directions over the surface, and therefore has no tendency to wear the road in one direction or place more than another; and the wheels acting in every direction, perform the part of rollers, to consolidate and keep the surface smooth. Hence a convex section wears better in the town than in the country, or better in places where the traffic is large and varied, than when it is small and of one description. Again, streets, where the convex section is most remarked, are wide, and the convexity shows; whereas in narrower roads, the rate of transverse fall being the same, the convexity would not be apparent. Indeed, thirty feet taken at the centre of Sackville Street would appear all but flat; the rise at the centre of that distance in several parts I have examined, being only one inch and three-quarters. But many wide streets or portions of them may be pointed out where the whole sections are nearly flat. These retain no water, and dry up as soon as streets, or the portions of them, where the sections are more convex.

Whatever force the reasoning for convexity in an old road may have, it will appear *that for new roads it entirely fails*, as any water falling on them passes through the metalling to the soleing, instead of running at the surface, where it is absorbed or discharged to the sides, according to the nature of the ground. If, as often happens, eight or ten feet at or near the centre of the road consolidates, after being first worked upon, the water may lie or run on the surface for so far, but after passing

Digitized by Google

this portion in its way to the sides, it escapes through the metalling of the unworked portion to the soleing as before. The draught is always least at the centre of convexity, but much more so in new than in old roads. I mean the difference of draught at the centre and sides of a new road, if convex, is greater than the like difference with the same convexity in an old road. This arises from the difference of weight on the lower wheel causing it to penetrate the metalling more in the new than the old. Hence, horses keep more at the centre of convexity in a new than an old road, and this portion soonest requires repairs. Experience shews that unless under very judicious management, these repairs raise the centre higher than before; and that, therefore, the convexity at the centre increases, instead of decreasing, as is often supposed. The tendency is, therefore, to an increase, not a diminution of convexity.

Now, suppose the new road to have a flat surface. *Firstly*, It is as well drained as the convex road, as the water passes through to the soleing in both cases, and continues to do so until the surfaces harden. *Secondly*, The surface being flat, vehicles pass nearly equally over the sides and centre, and the whole surface being therefore worked upon, it consolidates, *cæteris paribus*, in the shortest time possible, and the amount of draught and repairs are diminished; but as there will always be somewhat more work at the centre, there will be more repairs required there; and these can be effected so as to give a small degree of convexity to the road. The repairs will, for the time, throw most traffic to the sides, and after a short time the road will have a hard crust from table to table. I have tried these principles in a new road of about six miles in length, and after six months a crust was formed from side to side.

As the water escapes to the soleing in new roads, and as a road flat at the surface, to save metalling, ought to have nearly a flat sole, means must be had of taking off the water from it if not of a loose and dry nature. This is easily effected by having cross drains at about four perches, more or less, apart, about twelve inches wide, filled with metalling, having a fall of, say, one in eighteen to the sides, and passing under the fences to the grips, the metalling of the drains communicating with the metalling of the road. The cost would not exceed four or five pence the perch of road, and would be cheaper than forming the sole into a convex section as is most usual. These tables or drains help to drain the sole itself as well as carrying off the surface water that penetrates to it. (See plan, fig. 9.) When the surface is flat and the soleing flat the thickness of the stoning will at first be equal throughout. This will not add to the quantity of stones usually put on, as the depth at the centre is decreased, while that at the sides is increased, as is necessary from the consequent increase of traffic on that portion of the road arising from the flat section. During the first year's work,

Digitized by Google

the centre can be raised as high as may be deemed necessary, and to any cross section; in which case the soleing may have a like cross section. The three feet next the fences will not require more than three inches of broken stones; this should extend into the fence and under the table, unless paved, and may, without injury, have a slight fall, say two inches, or one in eighteen. The metalling strengthens the tables, and effectually hinders the cottiers and landholders along the road from cutting them away from year to year for the manure lodging and generated in them, until grips are formed, after a period, where none previously existed. Besides, a road appears cleaner, and can be kept so, that has stoned tables. Along steep declivities it is necessary that the depth of stones at the sides should be increased, for the further reason, that guides with heavy laden carts keep one wheel in a table coming down a hill for the purpose of increasing the draught and keeping off the pressure from behind. In fact, they use the tables as a sort of drag; and for the purpose of decreasing the draught going up, they turn the wheels alternately from table to table, while winding to lessen the inclination. When the tables in such cases are not protected, they are soon cut up, become uneven, and, during the next heavy rains, are sure to send a flood of water in one or more channels over the road.

With respect to the remedial measures best to be adopted in remodelling the cross sections of old but useful roads, presenting the appearance of figures 2, 3, 4, 5, 6, and 7, and widening them where required, I may mention that in Louth three methods have been adopted, singly or combined, according to circumstances. *Firstly*, By cutting away the small knolls or hills along the line, and raising the sides to the proposed widths with them. *Secondly*, Shaving off the high parts of the cross section, and raising with the stuff the lower portions. And, *Thirdly*, Splitting the road, lowering its surface, filling in the sides or grips with the stuff obtained, and new metalling the whole. The principle of all these is that the stuff required should be had in the road. Circumstances must guide as to which of these methods is to be used, but it will almost generally be found that the first is the best and cheapest: best, as in remodelling and widening the cross section the longitudinal section is improved; cheapest, as new surface materials have only to be put on where the knolls have been cut away; mostly short distances, and on the raised sides; the old surface, as far as it is in form, remaining as before. It will be necessary, however, to unite the second method with this; those parts of the old surface that are above, but close to the intended form, being picked into the parts below. The third method ought only to be used where it is necessary to lower the surface, or where stuff cannot otherwise be had cheaper; including the requisite metalling in both calculations. The first and second methods have been used in remodelling about twenty-five miles of roads in

Digitized by Google

Louth. The average cost, including the metalling, was about three shillings per perch; some perches requiring an expenditure as high as twelve shillings, and others none at all. In figures 2, 3, 4, 5, 6, and 7, the line *a*, *b*, shews the surface remodelled by the first and second methods, and the line *c*, *d*, by the third method. If a grip is a watercourse, or a partial one during the winter, the widening should be made on the opposite side, unless the course admits of being narrowed; if only a small quantity of water runs in the grip, it may be carried off by a pipe, as in figure 3. In the greater number of cases, however, the water lodging in grips is dead water, and collects from a want of fall. If the grips are filled, it will pass off without injury. In many instances these pools in grips are dangerous in winter from their depth, and in summer as reservoirs of miasmata and malaria. Even the grips on the field side of a fence, when not made with a continuous discharging fall at their bottom, are often injurious in this respect. Grips are, in many instances, serviceable to the underdrainage of the road, and in such cases they should be removed to the field side and the fence placed on their previous site.

Having endeavoured to show the necessity for a cross section nearly flat in roads up to thirty feet in width, I will now consider the practical considerations to which the degree of flatness is subject, and give in conclusion a general formula for the transverse fall of a road of any longitudinal degree of inclination. The surface form of a road varies from two causes: the application of materials, and the wearing down of the surface. If a flat road is not allowed to wear hollow, it must be coated. If stones are broken to about two inches, the first coat at the centre will raise that portion only about one inch and a half, as the angles of the stones will sink in the surface. A second coat will raise it say one inch and a half more; the double coat, applied at different times, making in all a rise of about three inches. By ordinary attention, these coats, applied in parts, and from time to time as required, can be laid on so as to make the fall regular from or near the centre to the sides. As no worn rut on a road, in proper hands, should ever exceed in depth the thickness of one coat of stones, the bottom of such a rut would never be below the sides or flat surface to which the two coats were applied; it would therefore be above the sides and tables. This is the most that is required, as drainage can be had from it by picking a small drain on the surface to the sides. Now as about six feet at the centre would practically wear flat, there would be about three inches fall for the remaining twelve feet on each side of a thirty foot road. This would give a transverse fall of one in forty-eight, and this I believe ought to be the *maximum* fall in the cross section of any road on a horizontal plane. If the longitudinal inclination is now taken into account, the arbitrary formula $\cdot 021 + \overline{\sin l}|^{\frac{3}{2}}$ will give the rate of transverse fall decimally expressed, l being

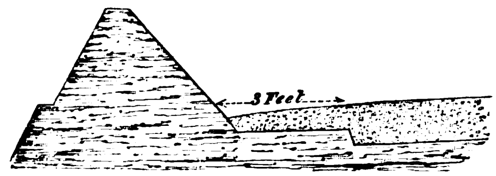
Digitized by Google

the longitudinal inclination in degrees. The formula gives one in forty-eight, as before, for the fall on a horizontal plane, and one in nineteen for a transverse fall on a rise of one in ten. On intermediate gradients, the transverse falls would also be intermediate, being, for instance, one in thirty-seven in a longitudinal fall of one in thirty. For the reasons before given, I do not, however, consider that the longitudinal fall ought to affect even so much the transverse fall, and in most cases not at all.

The state of the surface is a much more important consideration than the convexity of a road. Of all roads, a road too convex at the centre is the worst, and such a road is never worked upon all over, unless where the traffic is considerable and varied, or forced. Rain-water will always be sufficiently discharged to the tables after the inequalities of surface are filled up, with the smallest transverse fall. The principal consideration is therefore to keep the surface as smooth as possible and free from road dirt, by scraping or sweeping as required. It is true that the worn portion of a road nearly flat, as a worn rut, retains more water in it after rain than a like rut on a road which is more convex, or which has a greater transverse fall, as the water can escape better from the side next the table: but this is only a part of the whole consideration. Round roads are most worn at the centre, where the roundest are nearly flat, and there is there no fall to carry off the water; the ruts are therefore there deepest. In a road nearly flat, the wear and tear extends nearly alike over the whole surface. The wear and tear is therefore smoother, and the worn portions not so deep as at the centre of a road more convex. The wear and tear being less, the scrapings are less, and these in the state of dirt on the road form less obstruction to the water passing off. The greatest injury to roads arises from the surface not being kept clean, and from scrapings being allowed to remain on the shoulders. The water in this case is thrown back and kept on the road; this, and not want of convexity, is the reason why water may often lie on roads nearly flat. It may be remarked that water cannot lie long, or until evaporated or absorbed, in a worn rut, as it will be dashed out by the wheels of vehicles in passing, and being then extended over a greater surface than before, dries up sooner. The water absorbed by dirt lying on the surface does often more injury; as it evaporates more slowly, and the mixture keeping the surface soft underneath, causes it to wear down more rapidly; the dirt acting as a grinding material under the wheels.

With respect to water tables, where not paved, the most important thing in their construction is to have them stoned with about three inches of metalling, as before mentioned, and as shown in the annexed sketch. A fall of one in eighteen for the three feet next the fence, and beating down about six inches in width of the inner

Digitized by Google



portion an inch deeper, will make the table abundantly deep. A water table should always be kept clear, free from every obstruction, and from inequalities of bed where water may lie. The cost of outlets and inlets is so trifling, one should be at every change of longitudinal inclination, with as many between as necessary. If drains are required, they should be under the table and not in it. The strict use of a water-table being to convey the surface water off the road; a depth of two or three inches at most under the shoulder is quite sufficient for them. A water-table stoned to the fence can always be kept clean without alteration of form, but otherwise never; and places would soon be cut away for dead water to lie in, from the want of a hard bottom, in the operation of cleaning.

The conclusions to be drawn from the previous remarks I take to be as follows:—

Firstly, That the maximum transverse fall of any road should not exceed one in forty-eight.

Secondly, That in all roads of thirty feet in width, and under, any transverse fall less than one in forty-eight is sufficient.

Thirdly, That in all new roads of thirty feet in width, and under, the cross section should at first be flat and be raised afterwards by repairs.

Fourthly, That in the case of new wide streets, a fall of one in a hundred may at first be given with convenience and saving of stones, which may afterwards be increased by repairs if deemed necessary.

Fifthly, To save broken stones, the soleing of a new road should have the same cross section as it is intended the surface should have; or be flatter in proportion as the depth of stones at the centre is greater than at the sides.

Sixthly, The cross section may be, in form, either a flat segment of a curve, or inclined planes joined at or near the centre, as, practically, within the above limits, one form does not differ materially from the other.

Seventhly, That the transverse fall should continue uniform to within three feet of the fence at farthest; and that a fall of one in eighteen for this, three feet, or a depth of two inches, makes a water-table abundantly sufficient.

Eighthly, That in one-sided roads, a transverse inclination, from one side to the other, not exceeding one in forty-eight, will render such roads as convenient

Digitized by Google

almost as roads with a double fall; one-sided roads may therefore be adopted without inconvenience where necessary.

Ninthly, It having been shown that a flat road thirty feet in width is sufficient to discharge any rain-water falling on it, and that, including the practical conditions, a transverse fall of one in forty-eight ought not to be exceeded, half one in forty-eight, or about one in a hundred[a], will give a mean transverse fall between one in forty-eight and the horizontal to which the working of the surface should always tend, and which I think may be called the "mean standard cross inclination" at which to keep the surface. It is evident, however, that the transverse section and fall must always be subject to alterations within limits from wear and tear, and the application of new materials; and that want of scraping, sweeping, and of cleanliness in a road does more injury than want of convexity, by adding to the draught, wear and tear, and keeping water on the surface.

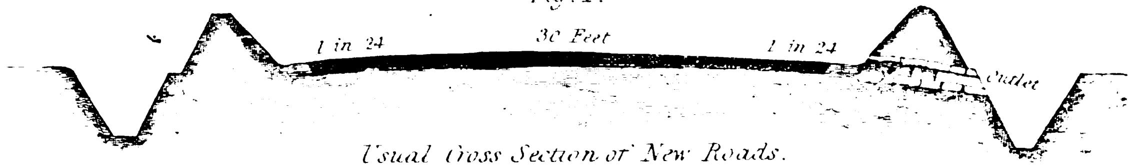
The cause of only sixteen feet in the centre of the Holyhead road being worked upon, as stated in the paragraph with which this paper commences, will now be understood to have arisen from over convexity, and not from the portions beyond not being paved.

Dundalk, November, 1844.

[a] The fall in the middle portion of Sackville Street, Dublin, for fifteen feet from the centre, averages at one in one hundred and three.

Digitized by Google

Fig. 1.



Usual Cross Section of New Roads.

Cross Sections of Some Old Roads.

Fig. 2.

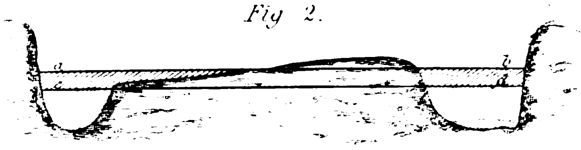


Fig. 3.

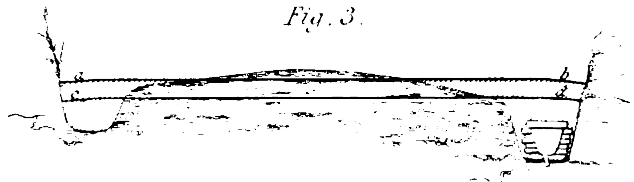


Fig. 4.

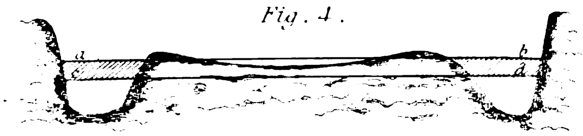


Fig. 5.

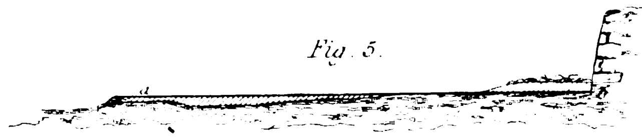


Fig. 6.

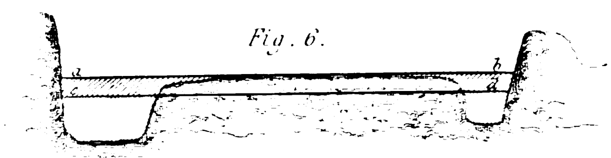


Fig. 7.

Fig. 8.

Proposed Cross Section as to Roadway only

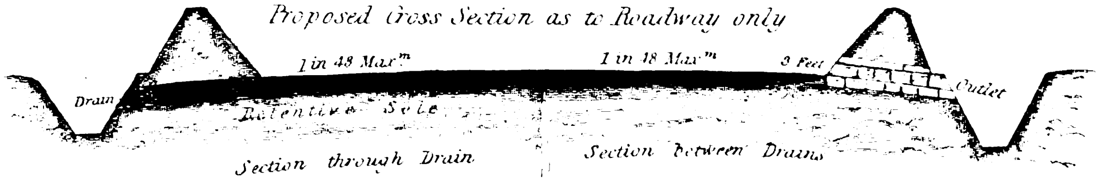
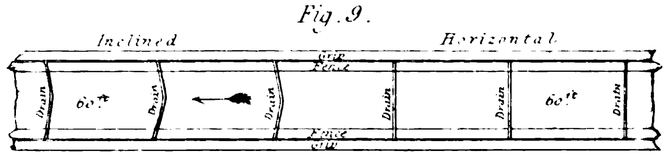


Fig. 9.



Plan of Roadway and Drains

S. Porter, sc.

London: John Weale, 1845.

Digitized by Google
Deutsches Museum
Bibliothek

Digitized by Google

ON THE

MANUFACTURE OF BRICKS AND TILES IN HOLLAND.

BY HYDE CLARKE, C.E.

CONSIDERABLE interest attaches to the manufacture of Dutch bricks, and I have made several enquiries on the subject, but I was not able to find any recent publications in Dutch; and I have not found, in what I have seen, that there is any modification adopted of the old process, which has been fully described by a competent authority, but which, as it is not accessible in an English shape, I translated for my own use, and that of my friends, some time ago; and now, at the request of the Editor of these Papers, have placed in his hands for publication. It is not to be expected that any great novelty is to be found in this description, although minute details are given. Most of the Dutch processes have remained the same for centuries, and depend less for their success on any novel principle than on careful and continuous manipulation. The Dutch carry out great works, but cannot be called great Engineers, and although parsimonious, can scarcely be considered truly economical. We have nothing to learn from them in the way of grand operations, or contrivances for economizing labour. They proceed upon what is called the slow and sure plan, which is not always the cheapest; while it should be borne in mind that saving is not always economy: a judicious outlay is often the best means of securing a return, and the want of powerful tools and machinery generally in the long run loses money. Still there is a good deal to be learned from them in the choice of materials, and the arts of manipulation; for if not enterprising, they are careful in what they undertake. Sometimes, too, a circumstance, trivial in itself, suggests to the practical man a new idea, a new application, or the correction of some existing abuse; at any rate it can do us no harm to know what our neighbours are about.

I.—BRICKS.

The Dutch make a most extensive use of bricks, of which they have several kinds. Not only are bricks used for ordinary building purposes, and for furnaces, but also in great quantities for foot pavements, towing-paths, streets, and high roads. It may be

Digitized by Google

observed, that they have of late been used very effectively in this country for the pavement of railway stations. The paving bricks, or Dutch clinkers, are the hardest sort, and are principally manufactured at Moor, a small village about 2 miles from Gouda, in South Holland. The brick-fields are on the banks of the river Yssel, from which the chief material is derived, being no other than the slime deposited by the river on its shores, and at the bottom. The slime of the Haarlem Meer is also extensively used for this purpose, as most travellers know. This is collected in boats, by men, with long poles having a cutting circle of iron at the end, and a bag-net, with which they lug up the slime. The sand is also obtained by boatmen from the banks of the river Maes. It is of a fine texture, and greyish colour. The hard bricks are made with a mixture of this slime and sand, but in what proportions I am not informed. River sand is recognised as one of the best materials for bricks, and is used by the London brickmakers, who obtain it from the bottom of the Thames, near Woolwich, where it is raised into boats used for the purpose. For what are called in France Flemish bricks, and which are manufactured in France, Flanders, and on the corresponding Belgian frontier, river sand is preferred, and is obliged to be obtained from the Scheldt. At Ghent, and lower down, a considerable traffic is carried on in the supply of this material. The quantity used there is about one cubic foot of sand per cubic yard.

The slime and sand, being mixed, are well kneaded together with the feet, and particular attention is paid to this part of the process. The mixture is then deposited in heaps. The mode of moulding and drying is similar to that used elsewhere. Paving bricks are generally about 6 in. long, 4 in. broad, and $1\frac{3}{4}$ in. thick. Dutch clinks made in England are 6 in. long, 3 in. broad, and 1 in. thick.

The house bricks and the tiles are made for the most part at Utrecht, in the province of the same name, from brick earth found in the neighbourhood. House bricks are about $9\frac{1}{2}$ in. long, $4\frac{1}{2}$ in. wide, and nearly 2 in. thick.

II.—BRICK-KILNS.

The kilns are built of different sizes, but generally on the same plan. Sometimes they will take as many as 1,200,000 bricks. A kiln for burning 400,000 bricks at once is represented in the 'Memoirs of the Academy of Sciences of France.' It is a square of about 33 or 35 ft. long by 28 or 30 ft. wide, closed in with four walls of brick, 6 ft. thick at the base, and which slope upwards outside to their extreme height, which is about 18 ft. Some slope also slightly inwards, but in a different direction. Different plans are nevertheless adopted with regard to the form of the external walls, the great object being, however, to concentrate the heat as much as possible. In the

Digitized by Google

walls, holes are left for six flue-holes, and sometimes for eight or ten or twelve. In one of the walls, in the breadth of the kiln, an arched doorway is made, about 6 ft. wide and 12 ft. high, by which the bricks are brought into the kiln. The arrangements as to the doorway are also subject to variation. The interior of the kiln is paved with the bricks, so as to present a level base. The walls are laid with mortar of the same earth from which the bricks are made, and with which they are also plastered inside; yet, notwithstanding the strength with which they are built, the great power of the kiln fire sometimes cracks them. The kilns, I would observe, are not usually covered in, but some of those for baking building bricks have roofs made of planks, and without tiles, to shelter them from the wind and rain. Others are provided with rush mats, which are changed according to the side on which the wind blows. The matting also serves for protecting the bricks against the rain, whilst the kiln is being built up. A shed, or hangar, is put up on each side of the kiln, in order to contain the peat turf, or to shelter the fire-tender, and to preserve the fires against the effects of wind. Such being the practice with regard to roofing, when the bricks are put into the kiln, a layer, or sometimes two layers, of burnt bricks is placed on the floor, laid lengthwise, about $\frac{3}{4}$ of an inch from each other, and so as to slope a little from the parallel of the walls, that they may the better support the upper rows, which are always laid parallel to the walls. This layer is covered with old rush mats, on which are arranged the dried bricks, which are laid without intervals between them. It is said that the mats serve to prevent the humidity of the soil from penetrating to the bricks while the kiln is being filled, which generally takes from about three weeks to a month. This row of burnt bricks is so placed as to leave channels or flues of communication with corresponding openings in the kiln walls. Six layers of dried bricks having been put down, the next three rows are made to jut over, so as to shut up the channels or flues. The layers are thus carried up to about forty-five in number, the last two being of burnt bricks, though in some kilns four layers of burnt bricks are used for closing in. The crevices are secured with brick earth or clay, on which sand is put; the door of the kiln is then closed with one or two thicknesses of burnt brick, then an interval of about 10 or 12 inches filled in with sand, and this secured with walling, and by a wooden strut. The object of the sand is to prevent any of the heat from escaping through the crevices.

It is to be remarked, that in laying the bricks in the kiln, as they are laid down a cloth is put over them and under the feet of the workmen, so as to prevent any of the sand, which might fall off, from getting down and blocking up the interval or interstice which naturally remains between each brick, and so interrupting the passage of the flame, and causing an unequal heat or combustion in the kiln.

Digitized by Google

The kiln being filled, a sufficient quantity of peat turf is introduced into the flues, of which one end is closed up with burnt bricks, and the turf is set fire to. The turf used is from Friesland, which is reckoned better than Holland turf, being lighter, less compact, and less earthy, composed of thicker roots and plants, burning quicker and with plenty of flame, and leaving no ash. The general time in Holland during which the supply of turf by the flues is kept up is for about four-and-twenty hours, taking care at first to obtain a gradual heat, and supplying fresh turf about every two hours. The fireman, by practice, throws the turfs in through the small fire openings, and as far in as he judges necessary. When one side has thus been heated, the flue openings are closed, and the other ends opened for four-and-twenty hours, and supplied with fuel; and this alternate process is kept up for about three or four weeks, the time necessary to burn large bricks. In some kilns, however, the fire is kept up for five or six weeks, depending upon their size and the state of the weather. A fortnight or three weeks is, however, sometimes enough for the clinkers.

The burning having been concluded, about three weeks are allowed for cooling. It generally happens that the mass of brick sinks in in some places, arising partly from the diminution of volume produced by burning, and partly from the melting of some of the bricks which have been exposed to too great heat.

The quality of the bricks depends upon the degree of burning to which they have been subjected. Those from about a third from the middle of the top of the kiln, or near the centre, are black, very sonorous, compact and well shaped, breaking with a vitrified fracture. These are generally employed for cellars, reservoirs, and cisterns, and are most esteemed.

III.—TILES.

The tiles manufactured in Holland are flat, hollow, S shaped, or with a square opening in the middle to let in a pane of glass, being much used for lighting lofts and garrets all over the Low Countries. They are either red, grey, or blue, or glazed on one side only. The flat paving tiles are about 8½ in. square by 1 in. thick; they are used principally for cisterns and for bakers' ovens. The clay for tiles, it is to be noted, is in all cases more carefully prepared than that for bricks, being ground up wet in a pug-mill or tub, with a shaft carrying half a dozen blades. By this means, roots, grass, &c. are got rid of. The clay comes out of the pug-mill of the consistence of potters' clay, and is kept under a shed, where it is kneaded by women with their hands to the rough form of a tile, on a table dusted with sand. These pieces are carried off to the moulders, who are two in number, a rough-moulder and a finisher. The tiles are then dried under sheds, and afterwards in the sun. With regard to the flat

Digitized by Google

paving tiles, they are at first rough-moulded about an inch larger than the subsequent size, and a little thicker, and then laid out to dry under a shed, until such time as the thumb can hardly make an impression on them. They are then taken to a finishing-moulder, who, on a table quite level and slightly dusted with sand, lays one of the tiles, and strikes it twice or thrice with a rammer of wood larger than the tile, so as to compress it. He then takes a mould of wood, strengthened with iron and with iron cutting edges, and puts it on the tile, which he cuts to the size. The mould is of course wetted each time it is used. The tiles are then regularly dried. In Switzerland and Alsace an iron mould is used.

IV.—TILE-KILNS.

The tile-kiln is generally within a building, and about 16 ft. long, (in ordinary dimension,) 10 ft. wide, and 10 ft. high. The walls are from 4½ to 5 ft. thick, secured outside with great beams, and so secured together as to form a square frame. Some of the largest of them are pierced with four flue-holes, as in brick-kilns; but the flues are formed by a series of brick arches, about 2½ ft. wide by 16 in. high. The opening of the flue-hole is about 10 in. by 8 or 9 high. On their upper surface, these series of arches form a kind of grating, on which the tiles are laid. The kiln is covered in at top with a brick arch, pierced with holes of different sizes. The kilns are charged from an opening which is constructed in one of the side walls, and which opening is, of course, during the burning, blocked up and well secured. The fuel used is turf, as in the brick-kilns, and the fire is kept up for forty hours together, which is considered enough for the burning. Three days are then allowed for cooling, and they are afterwards taken out of the kiln. Those tiles which are to be made of a greyish colour are thus treated. It having been ascertained that the tiles are burnt enough, and while still red-hot, a quantity of small fagots of green alder with the leaves on is introduced into each flue. The flue-holes are then well secured, and the holes in the roof each stopped with a paving tile, and the whole surface is covered with 4 or 5 inches of sand, on which a quantity of water is thrown, to prevent the smoke from escaping any where. It is this smoke which gives the grey colour to the tiles, both internally and externally. The kiln is then left closed for a week, when the sand is taken off the top, the door and roof-holes are opened, as also the flue-holes, and the charcoal produced by the fagots taken out. Forty-eight hours after, the kiln is cool enough to allow of the tiles being taken out and the kiln charged again. Whenever any of the tiles are to be glazed, they are varnished after they are baked; the glaze being put on, the tiles are put in a potter's oven till the composition begins to run.

Digitized by Google

The glaze is generally made from what are called lead ashes, being lead melted and stirred with a ladle till it is reduced to ashes or dross, which is then sifted, and the refuse ground on a stone and resifted. This is mixed with pounded calcined flints. A glaze of manganese is also sometimes employed, which gives a smoke-brown colour. Iron filings produce black; copper slag, green; smalt, blue. The tile being wetted, the composition is laid on from a sieve.

The manufacture of tiles, as already observed, is principally carried on near Utrecht, in the province of Holland, which, like most of the great cities of Holland, has facilities for the transportation of its produce by water communication all over the country.

Gouda is a great seat of the pottery and tobacco-pipe manufactures, of which formerly Holland had a virtual monopoly, with regard to foreign trade, exporting largely Delft ware, Dutch porcelain, tobacco-pipes, bricks, Flanders' bricks, painted tiles, and paving tiles. The manufacture of painted tiles, for the decoration of the old fire-places, was very extensive; and an infinite variety of designs, principally on Scripture subjects, employed many humble artists. This, however, is almost of the past. The manufacture of tobacco-pipes was another great business, suitable to the consumption of tobacco by the Netherlanders. Gouda alone had, at one time, as many as three hundred establishments for the production of this article of trade. The manufacture of tobacco-pipes is still a large manufacture in England, much more considerable than is generally supposed, while manufactures of bricks and porcelain constitute a staple means of employment for many thousands of our population.

A great part of these descriptions, it will be seen, strictly apply to our own practice, and are trite enough and trivial enough; but in matters of this kind, there is nothing lost by being too minute, and it is always safe. In the present case, it is worth knowing these things, for the sake of knowing that there is no difference.

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google